FINAL

# Data Communication Network at the ASRM Facility

Third Year Final Report

February 5, 1994

IN-32-CR

9443

P-217

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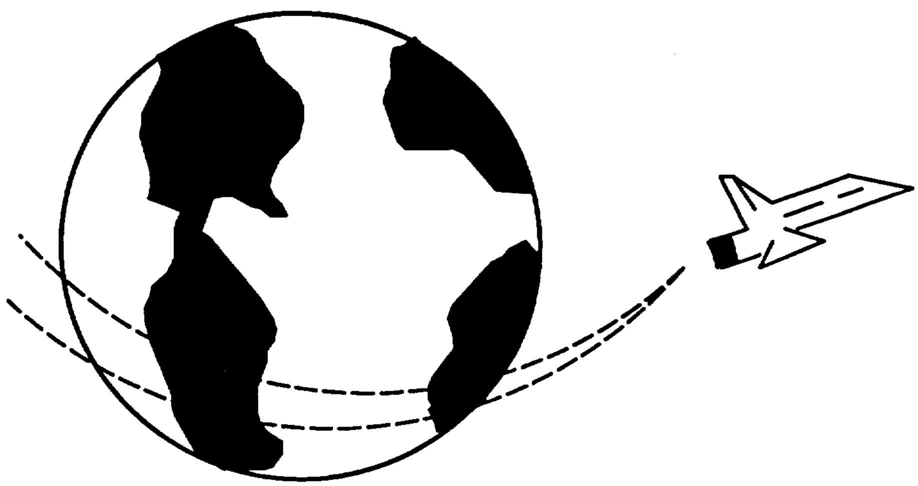

For the period : February 6, 1993 to February 5, 1994

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**NASA GRANT NAG8 – 866**

Submitted to

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**NASA / MSFC**

## ACKNOWLEDGEMENTS

Most of the information on the implementation details herein was obtained from Merlin Hill (AAD), Dale Scruggs (RUST), Kirk Weiss (RUST), and John Donaldsen (LMSC). Their assistance in providing information is graciously acknowledged.

The assistance of our NASA Technical Officer, Walter Robinson, is likewise acknowledged. Without his help, this study would be going nowhere.

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# 1. THE PROJECT

## 1.1 Introduction

This three–year project (February 1991 to February 1994) has involved analyzing and helping to design the communication network for the Advanced Solid Rocket Motor (ASRM) facility at Yellow Creek, near Iuka, MS. The principal concerns in the analysis were the bandwidth (both on average and in the worst case) and the expandability of the network.

As the communication network was designed and modified, a careful evaluation of the bandwidth of the network, the capabilities of the protocol, and the requirements of the controllers and computers on the network was required. The overall network, which was heterogeneous in protocol and bandwidth, needed to be modeled, analyzed, and simulated to obtain some degree of confidence in its performance capabilities and in its performance under nominal and heavy loads. The results of our analysis did have an impact on the design and operation of the ASRM facility.

## 1.2 Technical Issues

Throughout the whole process the most debilitating aspect was the lack of communication requirements. As is discussed in detail below, numerous redesigns were required primarily due to "new" or "changed" data rates, data quantities, or transmission duty cycles (e.g., 80MB not having to be transferred in 100 secs, but in 100 minutes). Insufficient priority was given to requiring the various "workcell owners" or "workstation users" to quantify their data transmission requirements.

We sought to evaluate the node connections; the I/O rates, the I/O rate characteristics (burst, steady, batch, etc.), and memory buffer storage capacity of each node; the physical lengths of cable; and the bandwidth of each LAN, the bandwidth of the backbone, and the bandwidth to communicate offsite. Initially our primary concern was the actual manufacturing area, but migrated to the Business Information System (BIS), since that became the most heavily loaded network ultimately.

### 1.3 Summary of Steps

A short summary of the interim final reports submitted in February 1992 and February 1993 and the rest of this final report is given below.

In February 1991, the proposed Manufacturing network consisted of an FDDI ring off of which were connected five Ethernet fiber–based LANs and the OIS computer. This configuration was analyzed, the results were summarized, submitted, and subsequently accepted as a refereed paper in the IEEE Southeastcon '92 conference. Several changes were made to the network as 1991 progressed. Once the OIS computer (a 4–machine VAXcluster) was procured, the FDDI ring disappeared and the 5 LANs were attached directly to the OIS computer. This configuration was simulated and the results discussed in Section 2 of the February 1992 interim final report. In July 1991, as the data rate requirements began to decrease, a data–over–voice network was proposed for non–critical sections of the network. The proposed network consisted of a hybrid of Ethernet–over–fiber and Intecom LANmark. This proposed network was discussed in Section 3 of the February 1992 interim final report. The two network technologies (Ethernet over fiber and LANmark) were tested on November 12–13, 1991 and on December 12–13, 1991 in Iuka, MS at the ASRM facility and the results are discussed in Sections 4 and 5 of the February 1992 interim final report. Section 6 of the February 1992 interim final report consisted of a summary and some conclusions on where the network stood and where the design seemed to be headed.

In early 1992 we performed an extensive study of the X protocol and its effect of its utilization on the network, due to the vendors "offer" to provide X–terminals in lieu of the ASCII terminals specified in the bid. We confirmed that by changing the end–user equipment from ASCII terminals to X–terminals, there would be a significant increase in the network traffic.

As 1992 progressed, the proposed network changed again. By January 1993, the overall network structure had one logical FDDI ring acting as a backbone for the whole complex. The buildings were grouped into two categories, namely manufacturing critical and manufacturing non–critical. The manufacturing critical buildings were connected via FDDI to the Operational Information System (OIS) in the main computing center in building 1000. The manufacturing non–critical buildings were connected by 10BASE–FL to the Business Information System (BIS) in the main computing center. The workcells were connected to the Area Supervisory Computers (ASCs) through the nearest manufacturing critical hub and one of the OIS hubs.

During 1993 we analyzed many configurations of this basic network structure. The analyses are described in detail in Section 2 and 3 herein. Section 2, Ravindra Nirgudkar's master's thesis, reports on an analysis of the whole network. The preliminary results of that research indicated that the most likely bottleneck as the network traffic increased would be the hubs. Thus a study of Cabletron hubs was initiated. The results of that study are in Section 3, which is James Dement's master's project.

Section 4 herein reports on the final network configuration analyzed. When the ASRM facility was mothballed in December of 1993, this was basically the planned and partially installed network.

A briefing was held at NASA/MSFC on December 7, our final analysis and conclusions were disseminated. This repor record of most of the information disseminated at that briefing

# 2. SUMMARY OF COMPREHENSIVE NETWORK ANALYSIS (RAVINDRA NIRGUDKAR'S THESIS)

## 2.1 Introduction

The thesis (Appendix A) analyzes the communication network for the NASA Advanced Solid Rocket Motor (ASRM) facility which was under construction at Yellow Creek near Iuka, Mississippi. Manufacturing, testing, and operations were to be performed in various buildings scattered over a 1800 acre site. These buildings were to be interconnected through a Local Area Network (LAN), which was to contain one logical Fiber Distributed Data Interface (FDDI) ring acting as a backbone for the whole complex. The network was to contain approximately 700 workstations, 22 workcells, and 3 VAX clusters interconnected via Ethernet and FDDI. The different devices would have produced appreciably different traffic patterns, each pattern would have been highly variable, and some patterns would have been very bursty. Most traffic would have been between the VAX clusters and the other devices. Comdisco's Block Oriented Network Simulator (BONeS) was used for network simulation. The primary evaluation parameters used to judge the expected network performance were throughput and delay.

## 2.2 Summary of the Thesis

The main aim of the thesis was to present the overall communication network structure for the ASRM facility. The thesis is composed of chapters discussing the ASRM communication network structure, the BONeS simulation of the ASRM network, and an analysis of the simulation results.

The chapter on 'ASRM Communication Network Structure' concentrates on the network connectivity, cabling, and the different protocols used. This chapter also explains the flow of data in the network.

The chapter on 'BONeS Modeling' gives an overview of the BONeS simulator. This chapter also describes the different BONeS models developed to simulate the ASRM environment and the different probes and the iteration settings used.

The 'Analysis and Results' chapter comments on the network expectations and the network evaluation parameters. The chapter also summarizes the various plots of Mean Delay and Throughput versus Traffic Intensity.

The 'Conclusion' chapter at the end of the thesis summarizes the different findings from the simulation results. The chapter also makes an attempt to validate the simulation model and verify the simulation results. A few recommendations for further study is also provided at the end of that chapter.

### 2.3 Research Objective

The main objective of the research was to simulate and analyze the network to determine its performance under different conditions. The performance of the network with the given topology and protocols can be evaluated using BONeS.

The two parameters viz. throughput and delay were used to judge the network performance. The aim of the simulations was to estimate the loading of the OIS, the BIS, the ASCs, and the network links due to the traffic generated by the workstations and the workcells over the entire site.

# 3. SUMMARY OF HUB ANALYSIS (JAMES DEMENT'S PROJECT)

## 3.1 Project Objectives

The objectives of this project were two–fold. The first objective of this project was to design and build a model of the Cabletron Hub using the Block Oriented Network Simulator (BONeS) which was developed by Comdisco Systems, Inc. The second objective was to use this model in a network simulation to try and determine if the hub produced any bottlenecks that might be of importance to network designers, especially those involved in building the computer network at the Advanced Solid Rocket Motors (ASRM) plant in Iuka, Mississippi.

## 3.2 Project Description

The computer network system at the ASRM plant used Cabletron Multi Media Access Centers (MMACs) for its network interconnection. By studying the documents provided by Cabletron Systems, Inc. and by talking with the Cabletron technical personnel, it was possible to develop an understanding of how the Cabletron Media Interface Modules (MIMs) used at the ASRM facility interacted with each other. Using this information and the BONeS Block Diagram Editor, models were developed that would emulate the interaction and timing specification of the overall hub. By connecting the individual modules together, the completed hub could be used in network simulations designed to analyze the performance of the hub.

## 3.3 Project Analysis and Conclusions

Using BONeS, models of the individual Media Interface Modules (MIMs) were developed. Tests were then conducted on these modules and the results of the tests were compared to known results. According to Cabletron documentation, the tests show that under all tested conditions, the software models produced the same performance measurements as the actual Cabletron Modules. This successfully concluded the first objective of the project.

The second objective, to use the models in a network simulation to determine delays caused by bridge processing, could not be completed in the time given. Although the second objective was not completed, it is possible to make predictions as to what the outcome might be by examining the results of the first objective. Tests in the first objective indicated the bridge modules could filter packets as fast as the protocols could deliver them. Therefore, little or no buffering would occur and the total delay would be negligible when compared to delays incurred by collisions and other network delays. Since the bridge modules could not forward packets as fast as they could filter them, there is a possibility that packets might need to be stored in temporary buffers in the bridges. Preliminary tests show that even under abnormally high traffic conditions, the buffers become at most 45% full.

### 3.4 Further Study

Although preliminary tests indicated that there should be no problem with the buffering capacity of the bridges, further study should be conducted to assess the delays incurred by the buffering. There are two hubs in particular that might pose a problem in the ASRM network. The first hub is the hub used to bridge one of the ASCs to the FDDI backbone. The second hub is the BIS hub where there are multiple 10 Mbps channels being fed into a single 10 Mbps channel.

# 4. NEW ASRM NETWORK

## 4.1 Introduction

On August 10, 1993, we were briefed in detail at the ASRM facility on the changes that had been made to the ASRM network up until that time. These changes were then incorporated into the existing network simulation and new simulations were performed. This chapter explains the changes made to the previous model, and compares the results of this new network model to those of the previous model.

## 4.2 Changes in the ASRM Network

- The two ASCs will be located one each in B_1000 and B_2029.
- Since one ASC is removed from B_1000, the whole of the workcell traffic will not be flowing to B_1000. The workcells attached to B_2029 will now have different paths (different then workstations paths) from their building to the ASC. The paths will be 10BASEFL.
- The ASCs will communicate with the OIS over the FDDI backbone.
- All the workstations in the intensive buildings will now be on the FDDI backbone, i.e., intensive buildings will no longer have a non–intensive hub.
- All the workstations connected to the purely non–intensive buildings will still communicate with the OIS through the BIS hub (same as before).
- The 73 workstations in B_1000 will now be connected to the BIS hub instead of the OIS hub.
- The following buildings have been deleted: B_1022, B_1025, B_1045, B_1032, B_2070, B_4001, B_3003, and B_3010.
- The following buildings have been added: B_1002 and B_2015.

### 4.3 New ASRM Network Structure

The new ASRM network structure will be as shown in figure 4.1 and 4.2.

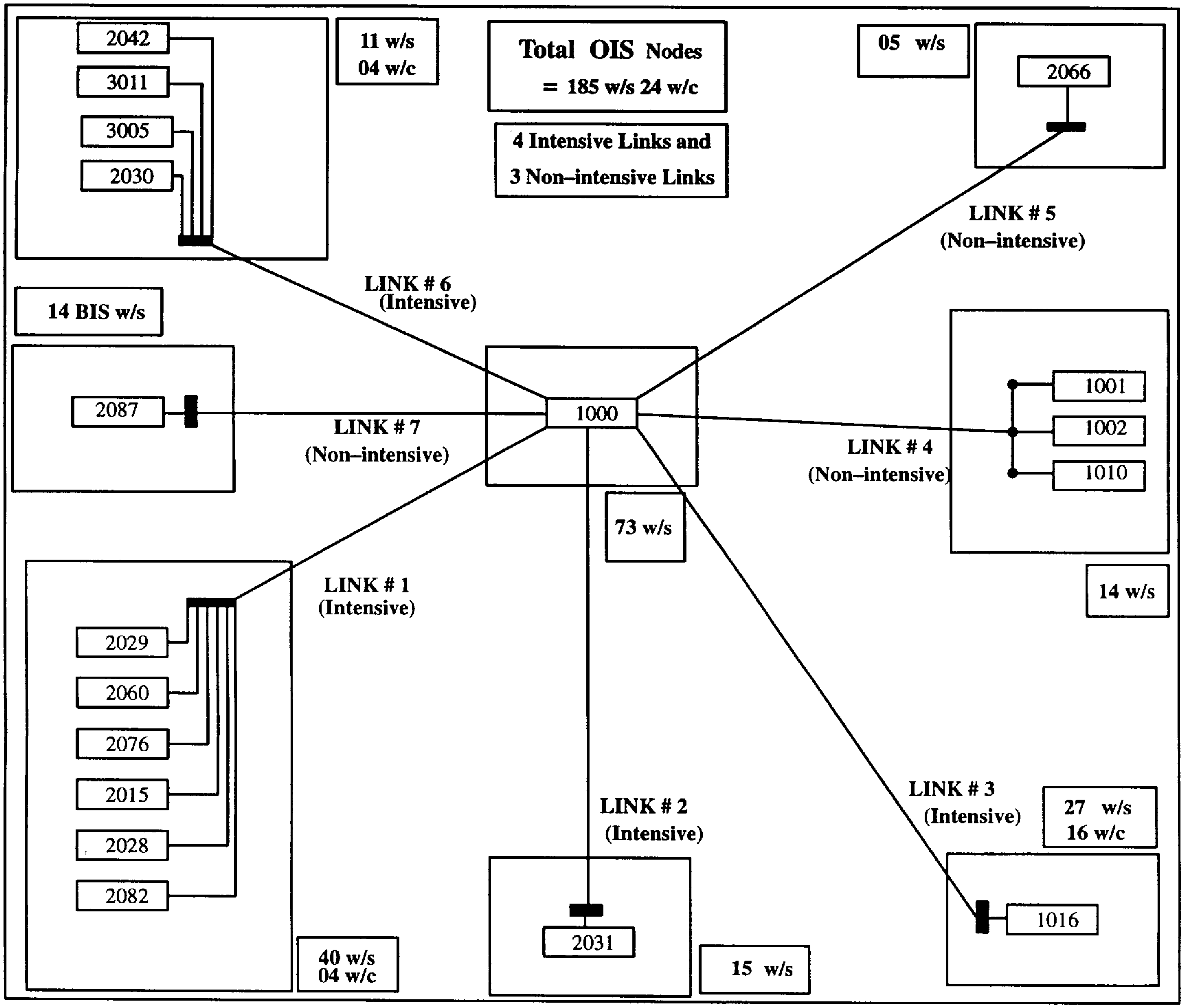


Figure 4.1 External building to building connections

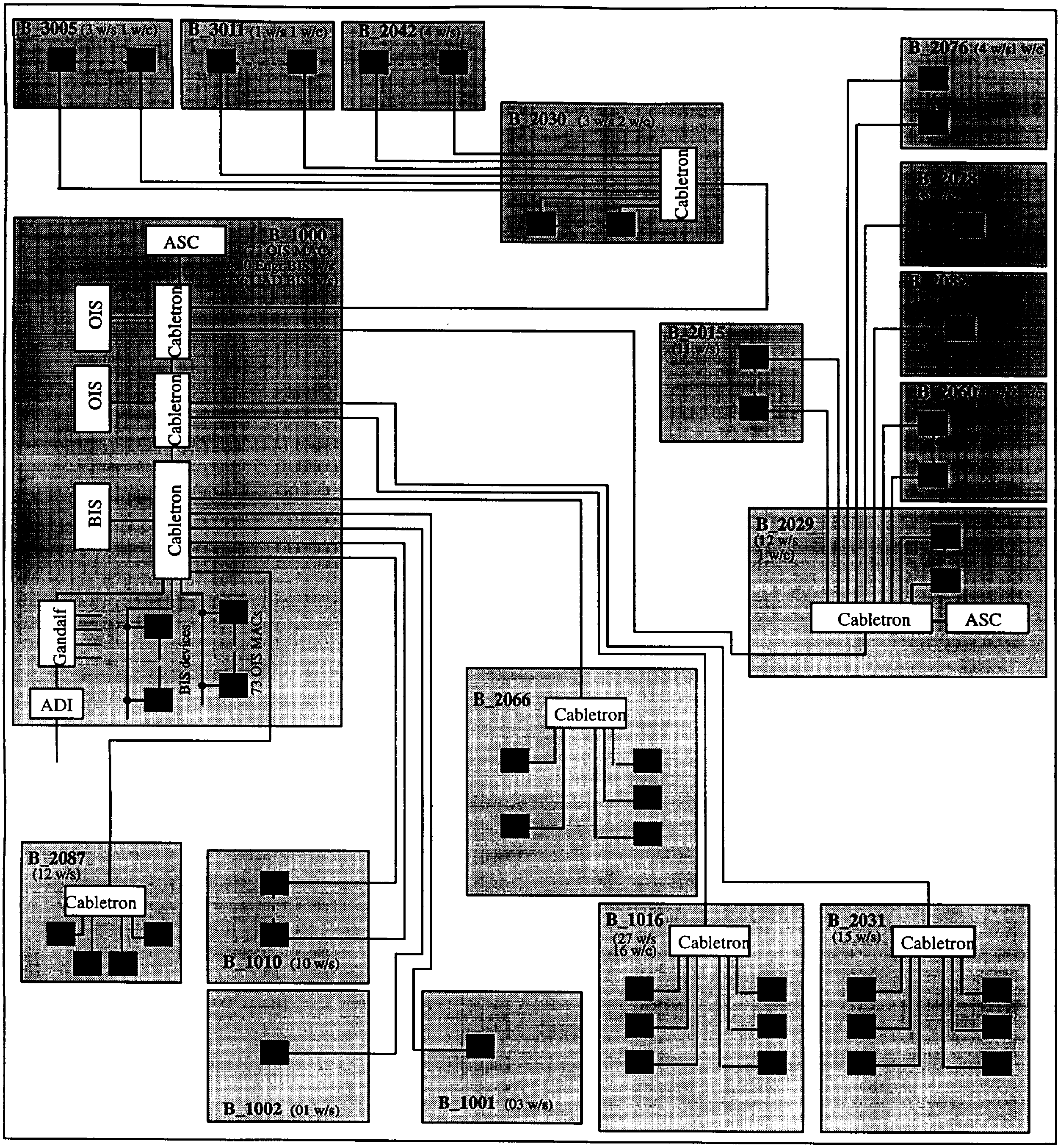


Figure 4.2 ASRM Yellow Creek Site as on 10/23/93

The distances of each building from the nearest hub and the distances of the hubs from building 1000 for the new ASRM network are as given in Table 4.1 and 4.2 respectively.

| Building No. | Building Name | No. of workstns | No. of workcells | Link | Nearest Hub | Distance from hub(feet) |
|---|---|---|---|---|---|---|
| 1000 | Engineering / Computer | 73 | 00 | — | 1000 | — |
| 1001 | Security and Medical | 03 | 00 | Link #4 | 1000 | 1500 |
| 1002 | Chemical Storage | 01 | 00 | Link #4 | 1000 | 2600 |
| 1010 | Central Warehouse | 10 | 00 | Link #4 | 1000 | 600 |
| 1016 | Case Prep. and Refurbishment | 27 | 16 | Link #3 | 1016 | — |
| 2015 | Pre – Mix (Mix / Cast) | 11 | 00 | Link #1 | 2029 | 1450 |
| 2028 | Tool Clean / Core Prep. | 08 | 00 | Link #1 | 2029 | 2600 |
| 2029 | Remote Control Room | 12 | 01 | Link #1 | 2029 | — |
| 2030 | Non Destructive Evaluation Facility | 03 | 02 | Link #6 | 2030 | — |
| 2031 | Final Assembly | 15 | 00 | Link #2 | 2031 | — |
| 2042 | Main Motor Storage | 04 | 00 | Link #6 | 2030 | 8650 |
| 2060 | Small Scale Propellant Proc. | 04 | 02 | Link #1 | 2029 | 2250 |
| 2066 | Quality Assurance Lab. | 05 | 00 | Link #5 | 2066 | — |

(continued on next page)

| Building No. | Building Name | No. of workstns | No. of workcells | Link | Nearest Hub | Distance from hub(feet) |
|---|---|---|---|---|---|---|
| 2076 | Qualification Motor Facility | 04 | 01 | Link #1 | 2029 | 2550 |
| 2082 | HTPB Storage Tank Farm | 01 | 00 | Link #1 | 2029 | 850 |
| 2087 | Warehouse 'A' | 14 BIS w/s | 00 | Link #7 | 2087 | — |
| 3005 | Control Building | 03 | 01 | Link #6 | 2030 | 5950 |
| 3011 | Feed Prep. Facility | 01 | 01 | Link #6 | 2030 | 6600 |
| | **TOTAL** | **185** | **24** | | | |

Table 4.1 Distances of each building from the nearest hub

| Link | Distance (feet) | Number of Workstations on the link. | Number of Workcells on the link. | Type of the Link |
|---|---|---|---|---|
| Link # 1 : (2029) | 6700 | 40 | 04 | Intensive |
| Link # 2 : (2031) | 4650 | 15 | 00 | Intensive |
| Link # 3 : (1016) | 1450 | 27 | 16 | Intensive |
| Link # 4 : (1000) | 00 | (14 + 73) + BIS Devices | 00 | Non–intensive |
| Link # 5 : (2066) | 3550 | 05 | 00 | Non–intensive |
| Link # 6 : (2030) | 5000 | 11 | 02 | Intensive |
| Link # 7 : (1012) | 950 | 14 BIS w/s | 00 | Non–Intensive |

Table 4.2 Distance of the hubs from Building 1000

### 4.4 BONeS models for the New ASRM Network

The BONeS models for the modified ASRM Network are as shown in figures 4.3, 4.4, 4.5, and 4.6.

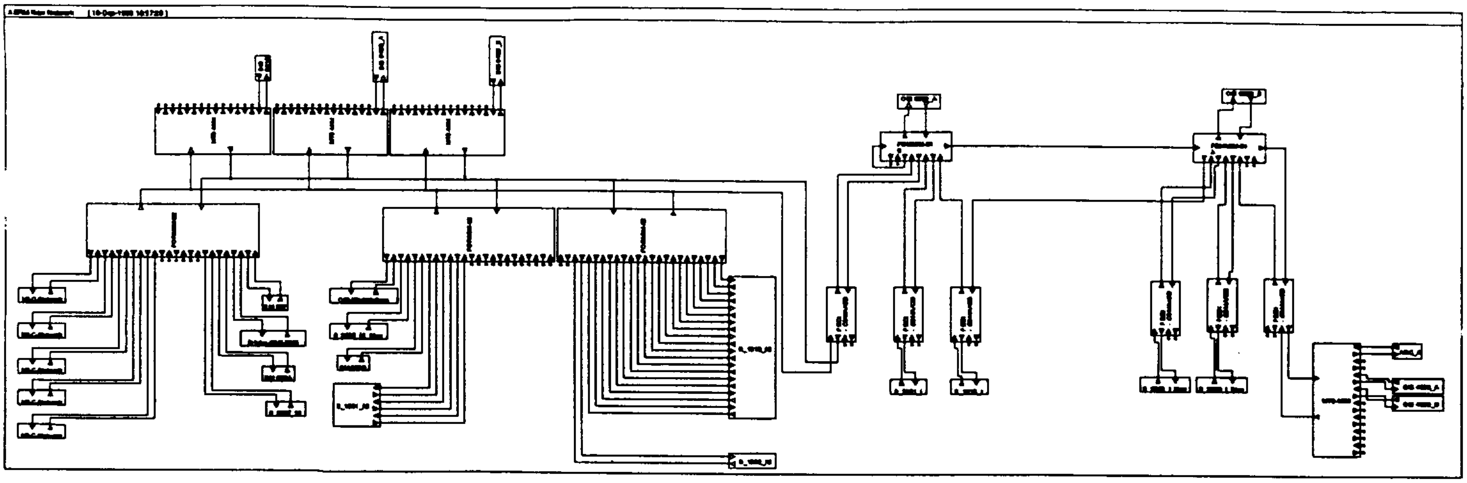

Figure 4.3 ASRM network Model

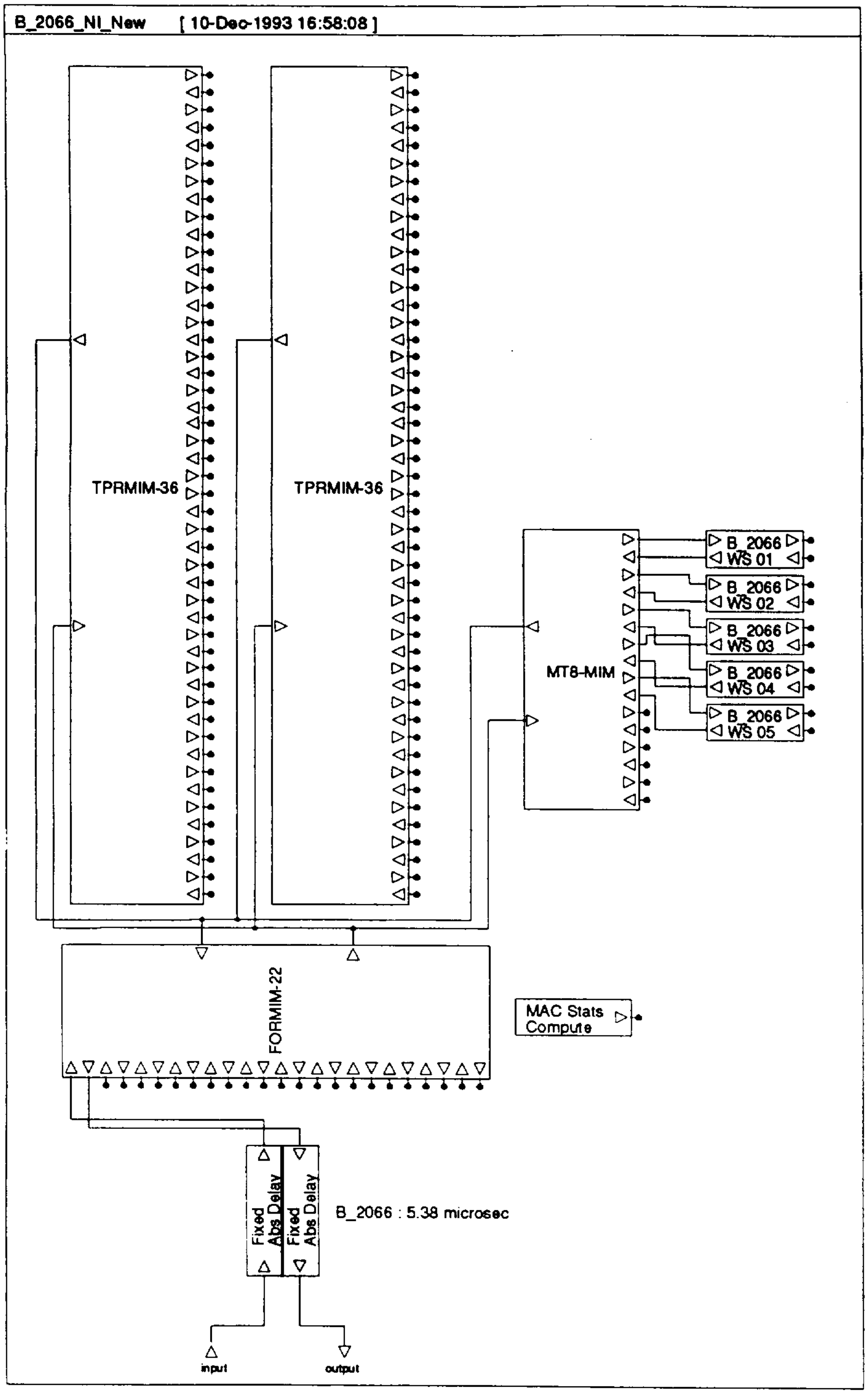


Figure 4.4 Non–Intensive building 2066 Model

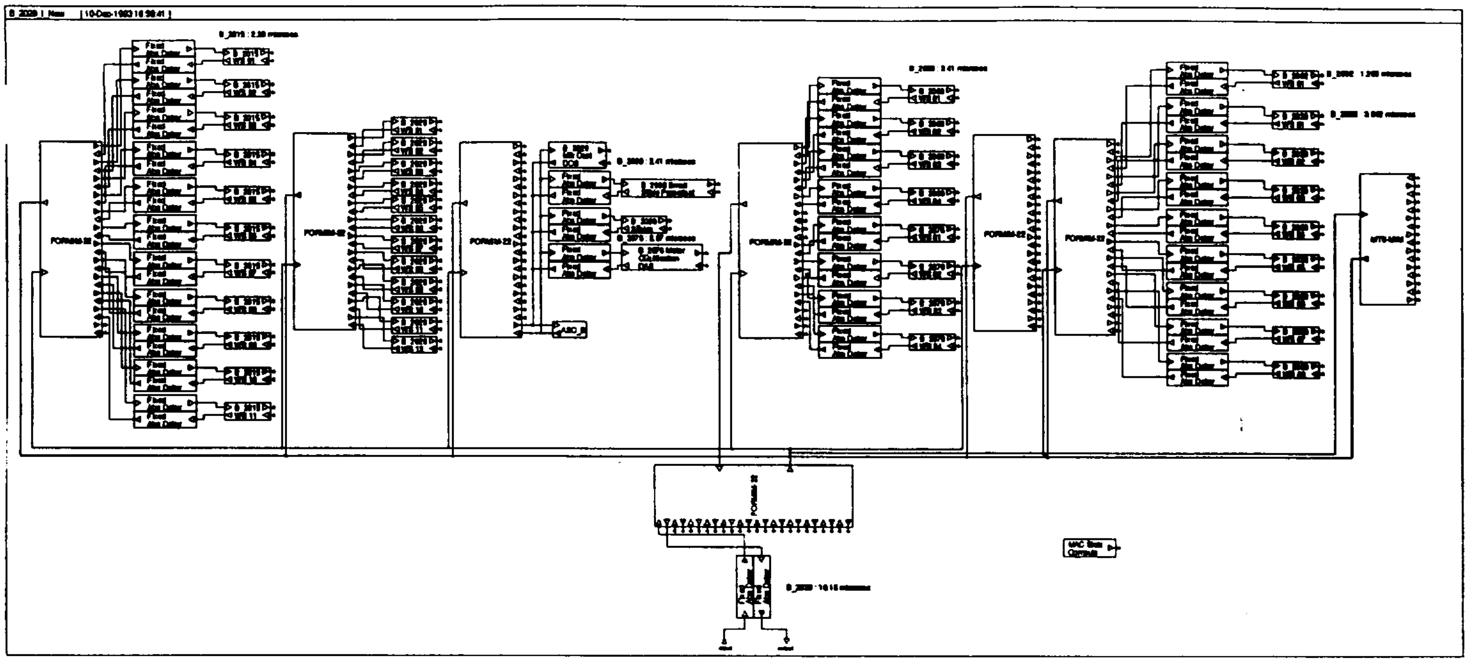

Figure 4.5 Intensive building 2029 Model

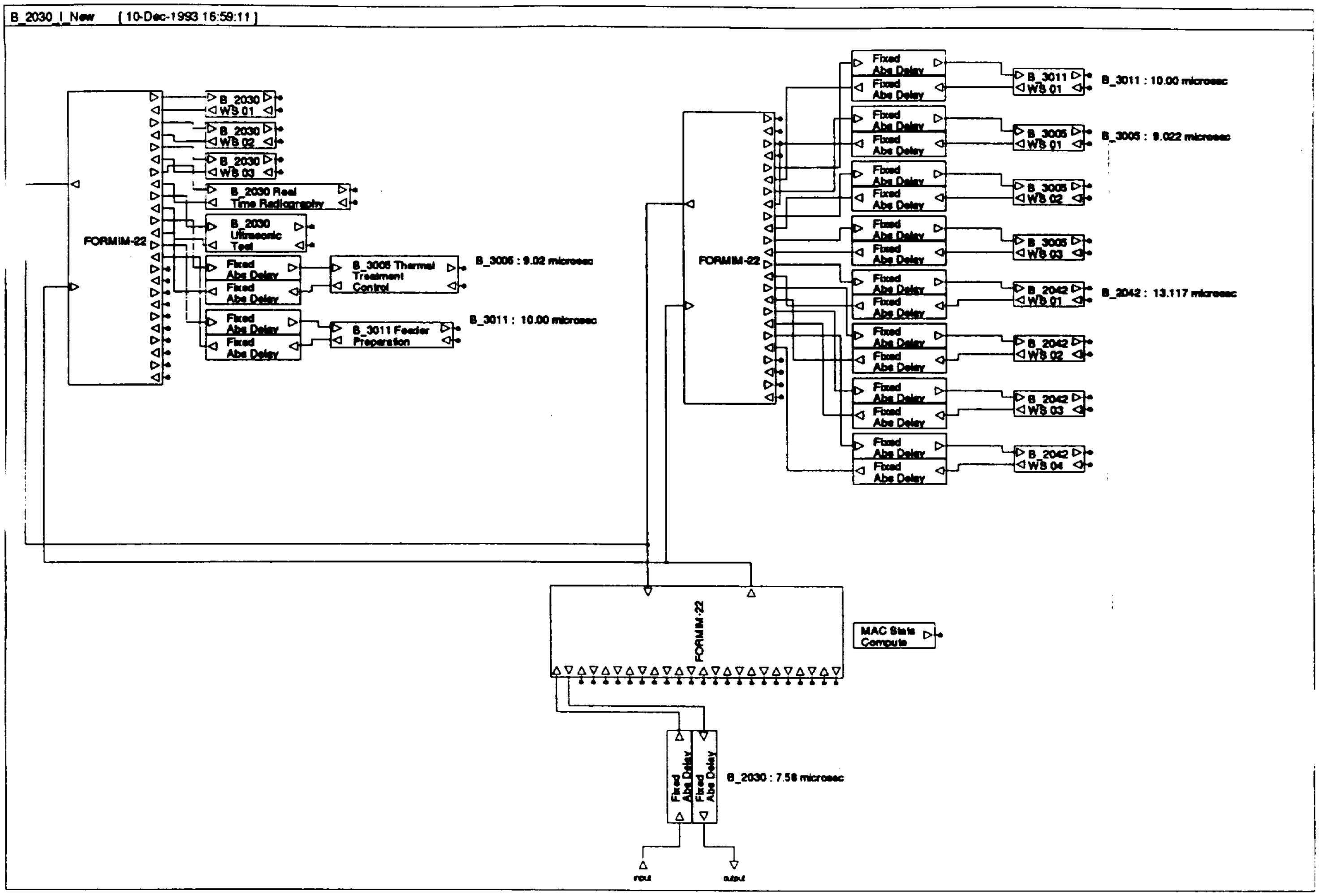


Figure 4.6 Intensive building 2030 Model

## 4.5 Mean Delay and Throughput plots

Various simulation runs were made on the new ASRM network model by setting the simulation time per iteration to one and five seconds. Also a simulation run of five seconds was made on the new ASRM network model without the BIS network to study the effect of the BIS network on the overall network. The mean delay per packet and throughput are plotted versus the offered traffic intensity. The mean delay per packet and throughput versus the offered traffic intensity are plotted in figures 4.7 to 4.22.

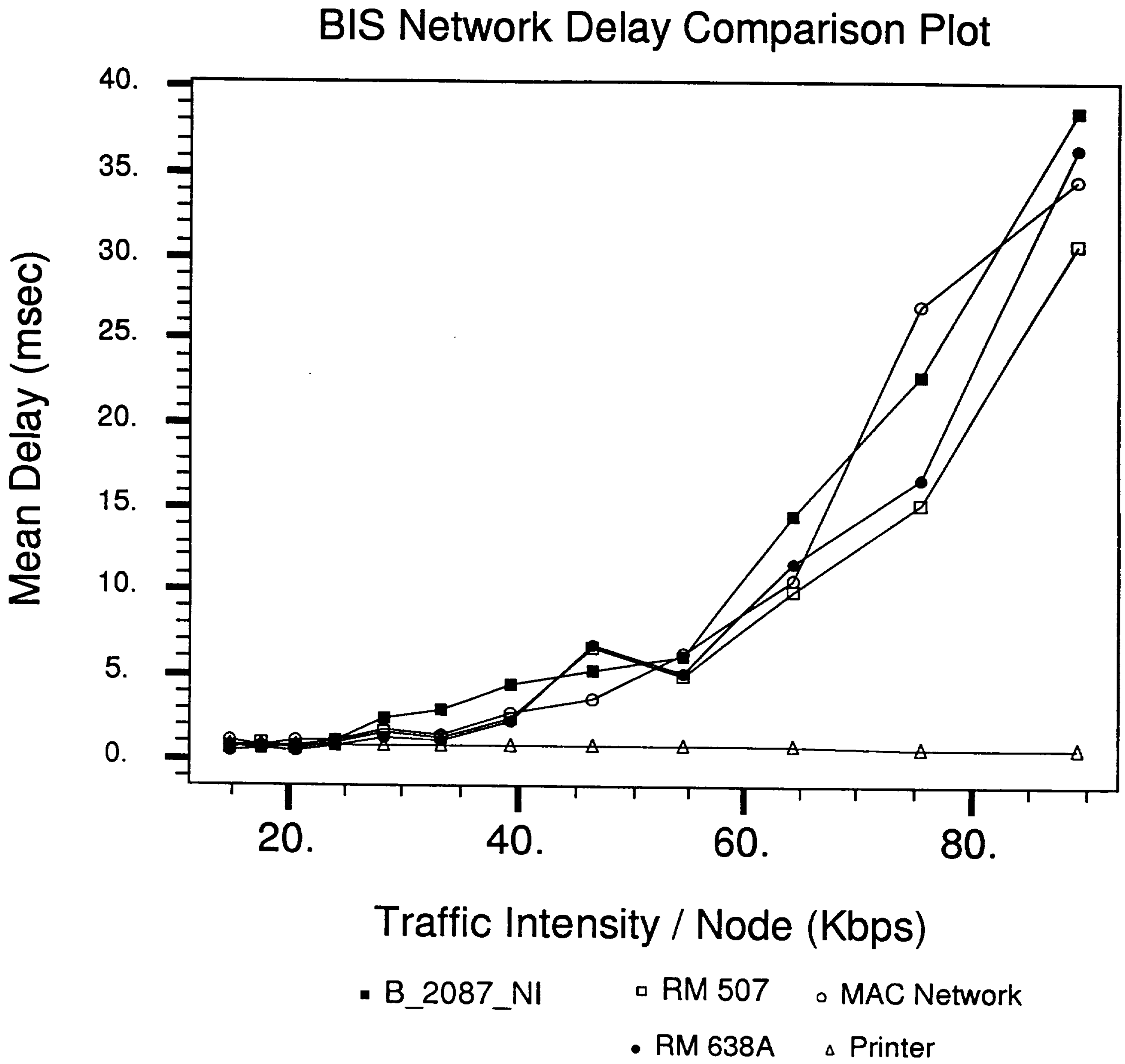


Figure 4.7 BIS delay plot for simulation time of 1 second

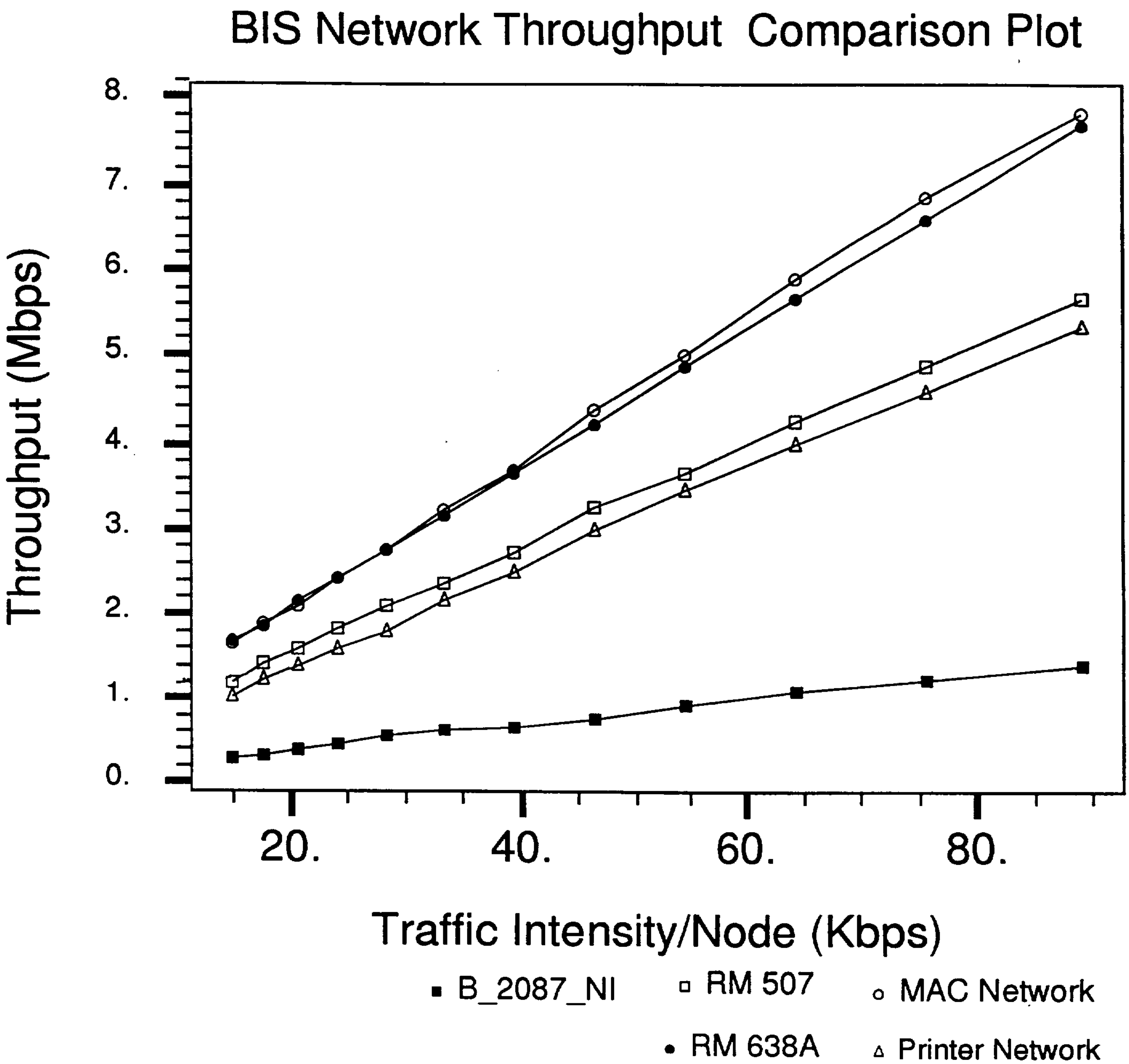


Figure 4.8 BIS devices throughput plot for simulation time of 1 second

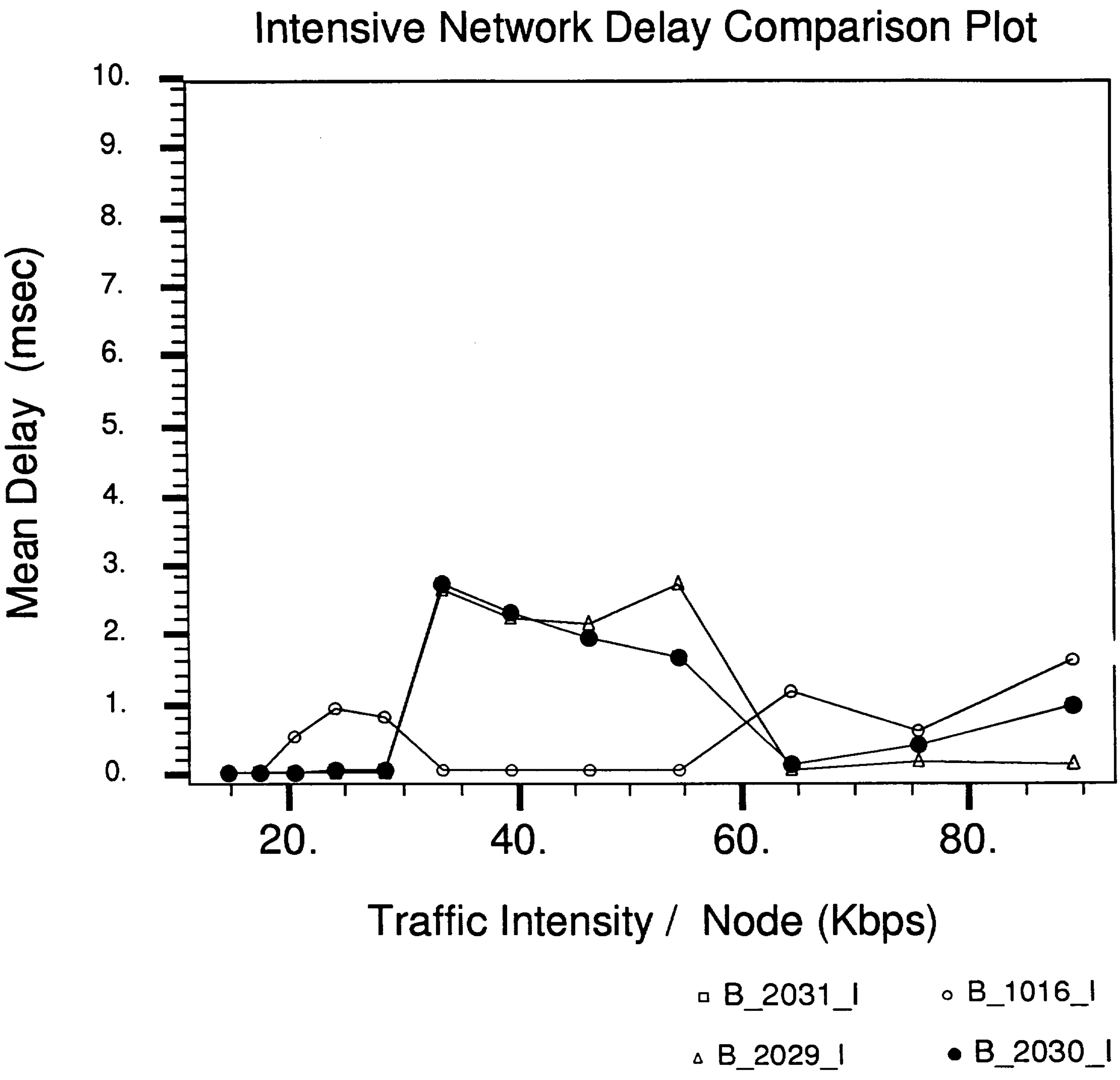


Figure 4.9 Intensive network delay plot for simulation time of 1 second

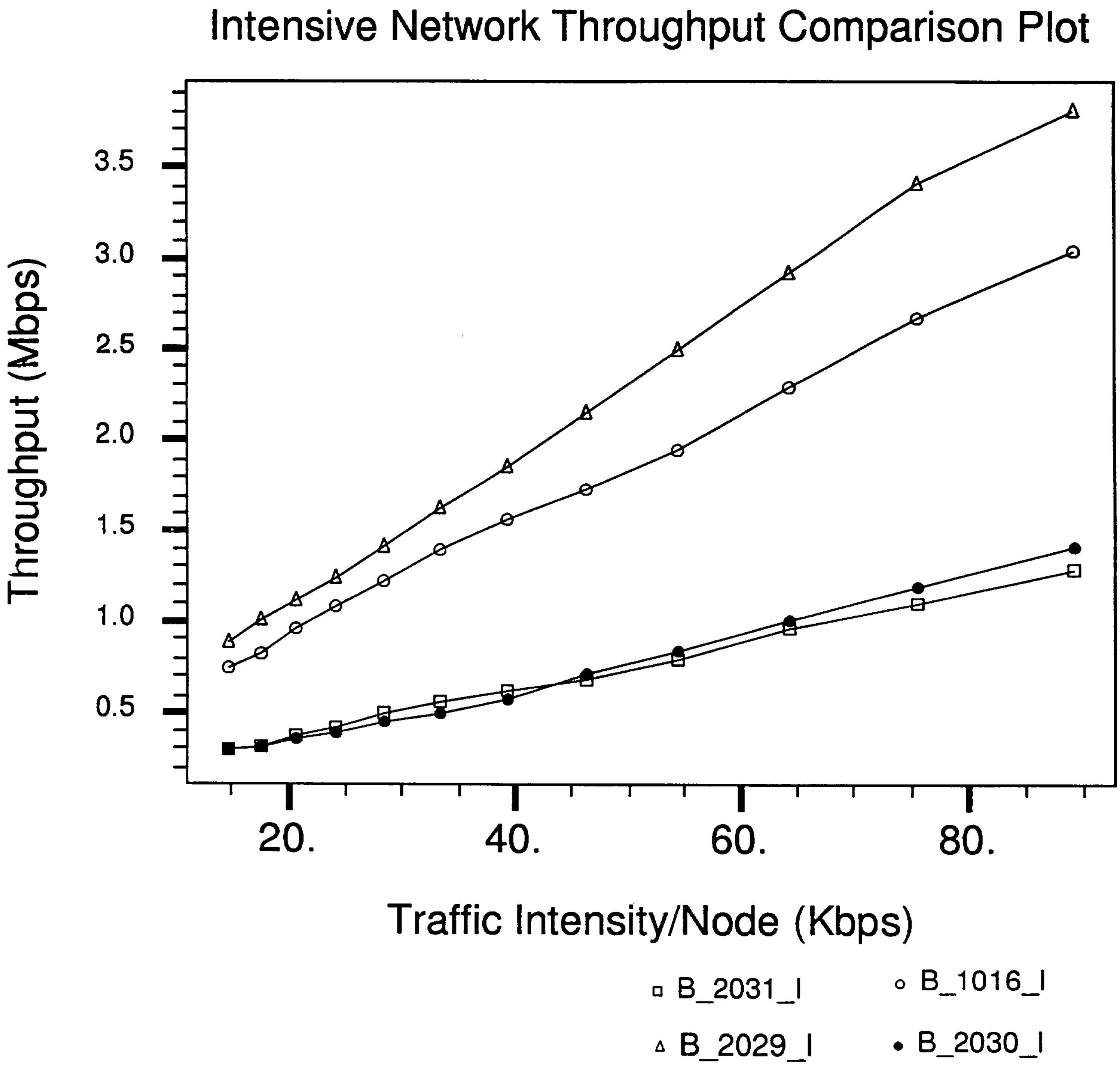


Figure 4.10 Intensive network throughput plot for simulation time of 1 second

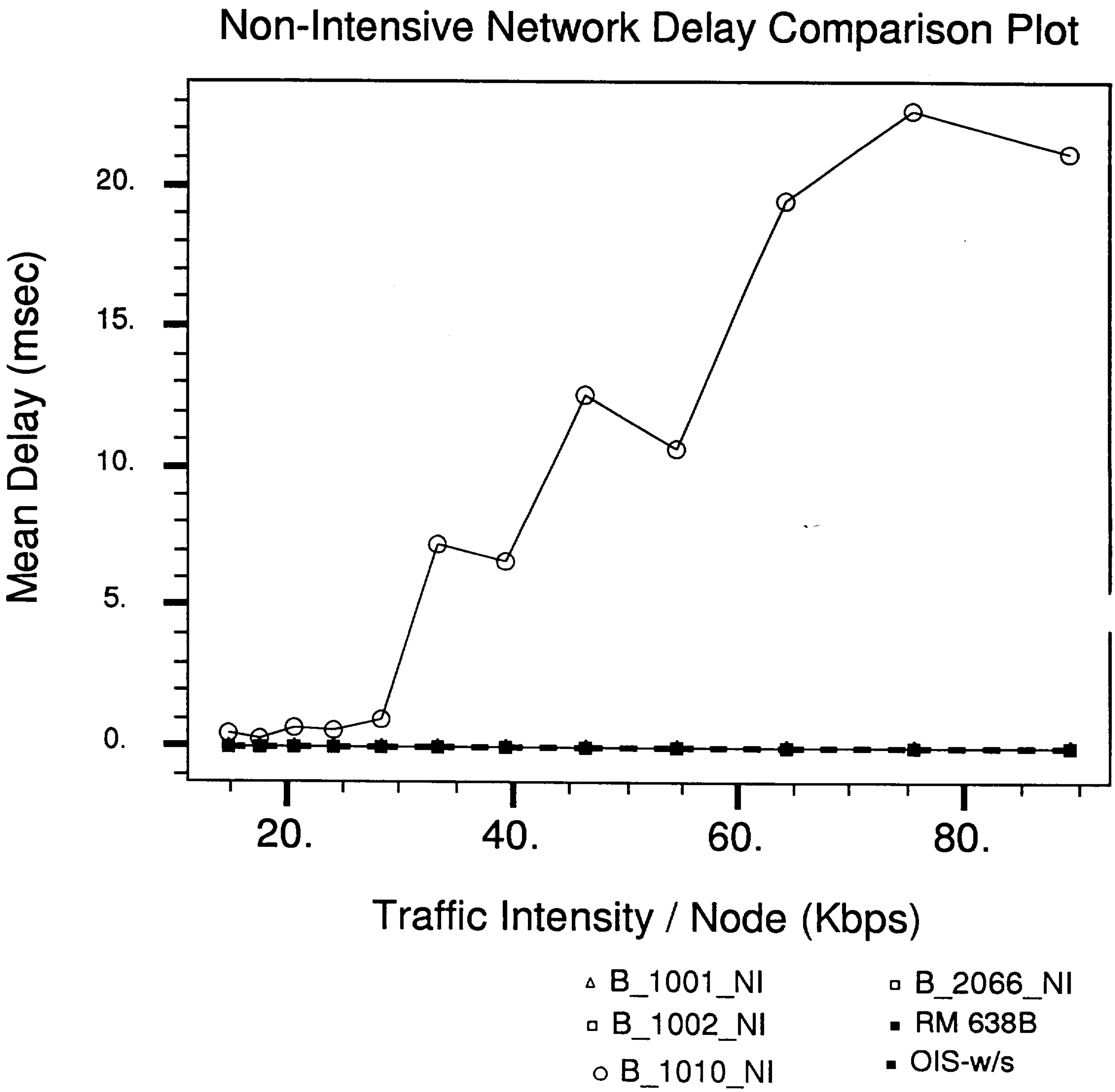


Figure 4.11 Non–Intensive network delay plot for simulation time of 1 second

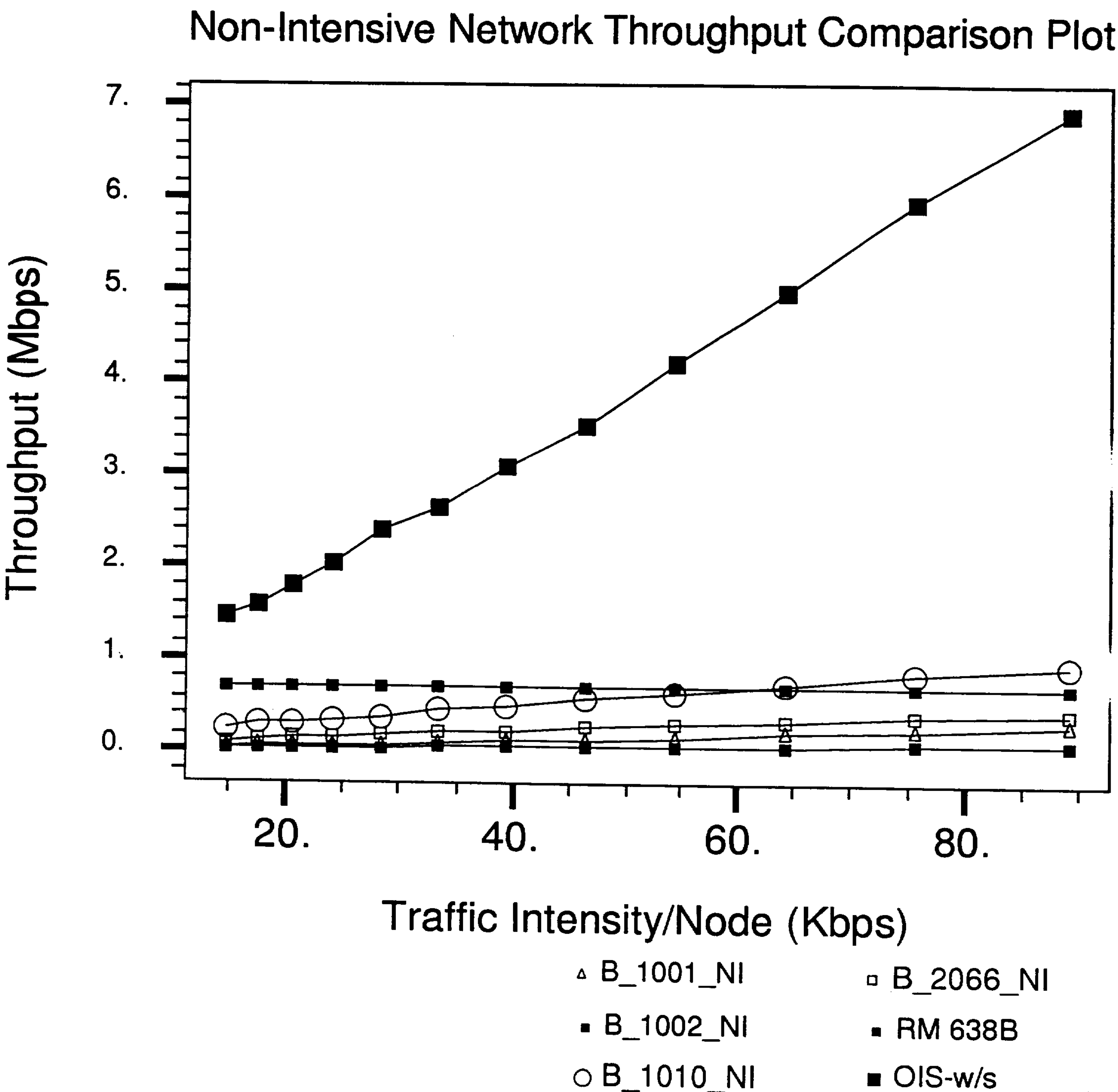


Figure 4.12 Non–Intensive network throughput plot for simulation time of 1 second

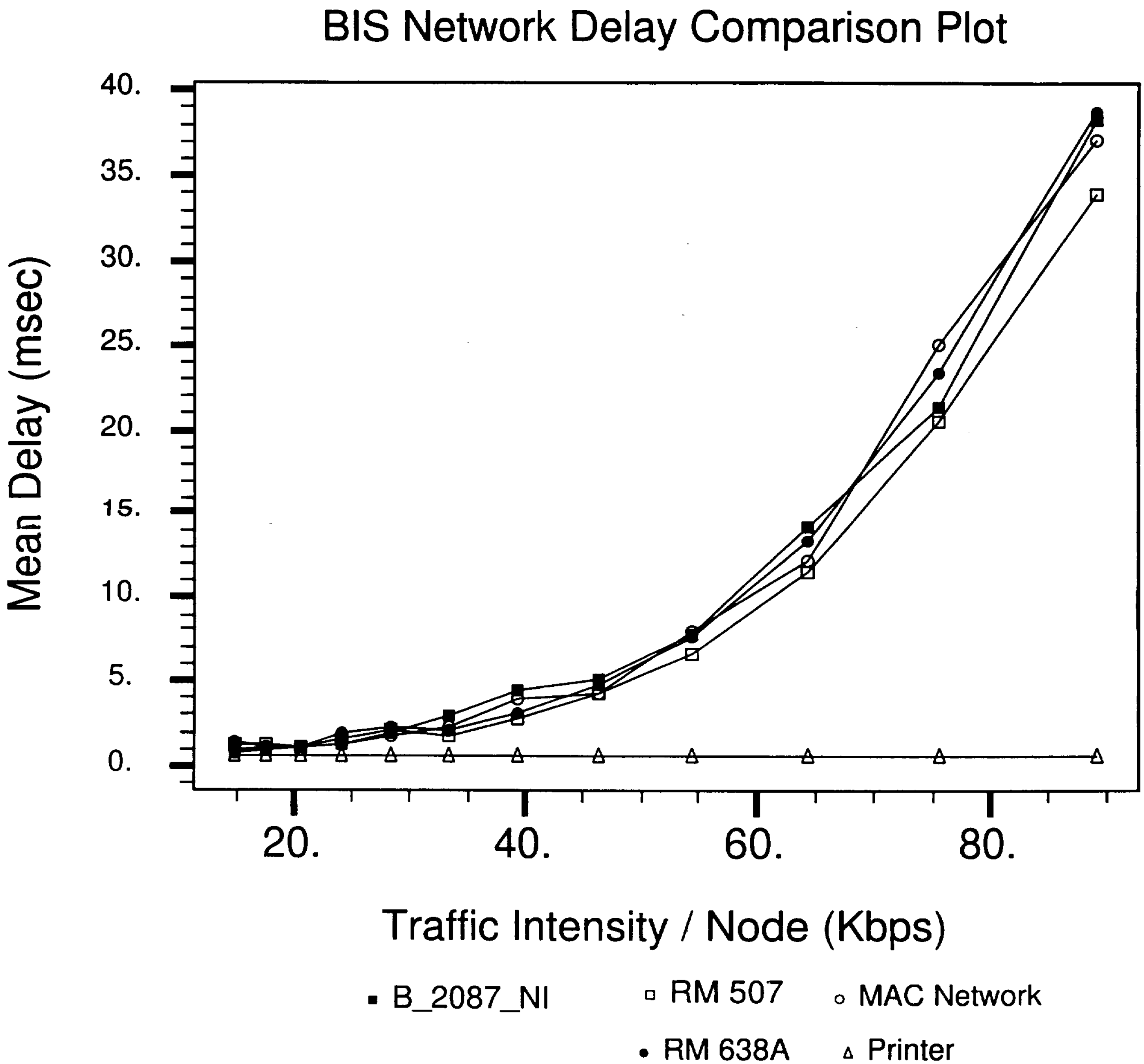


Figure 4.13 BIS devices delay plot for simulation time of 5 seconds

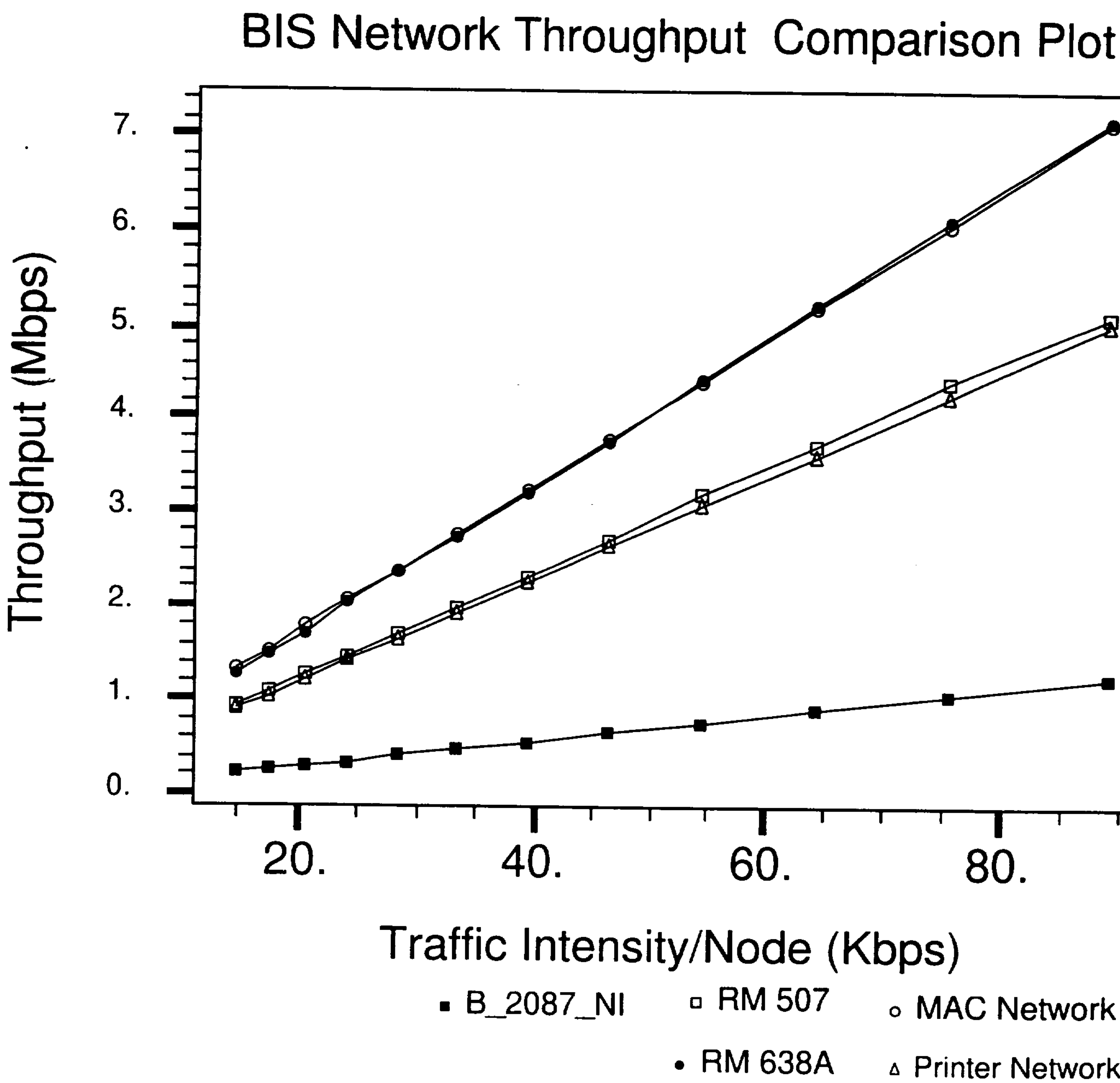


Figure 4.14 BIS devices throughput plot for simulation time of 5 seconds

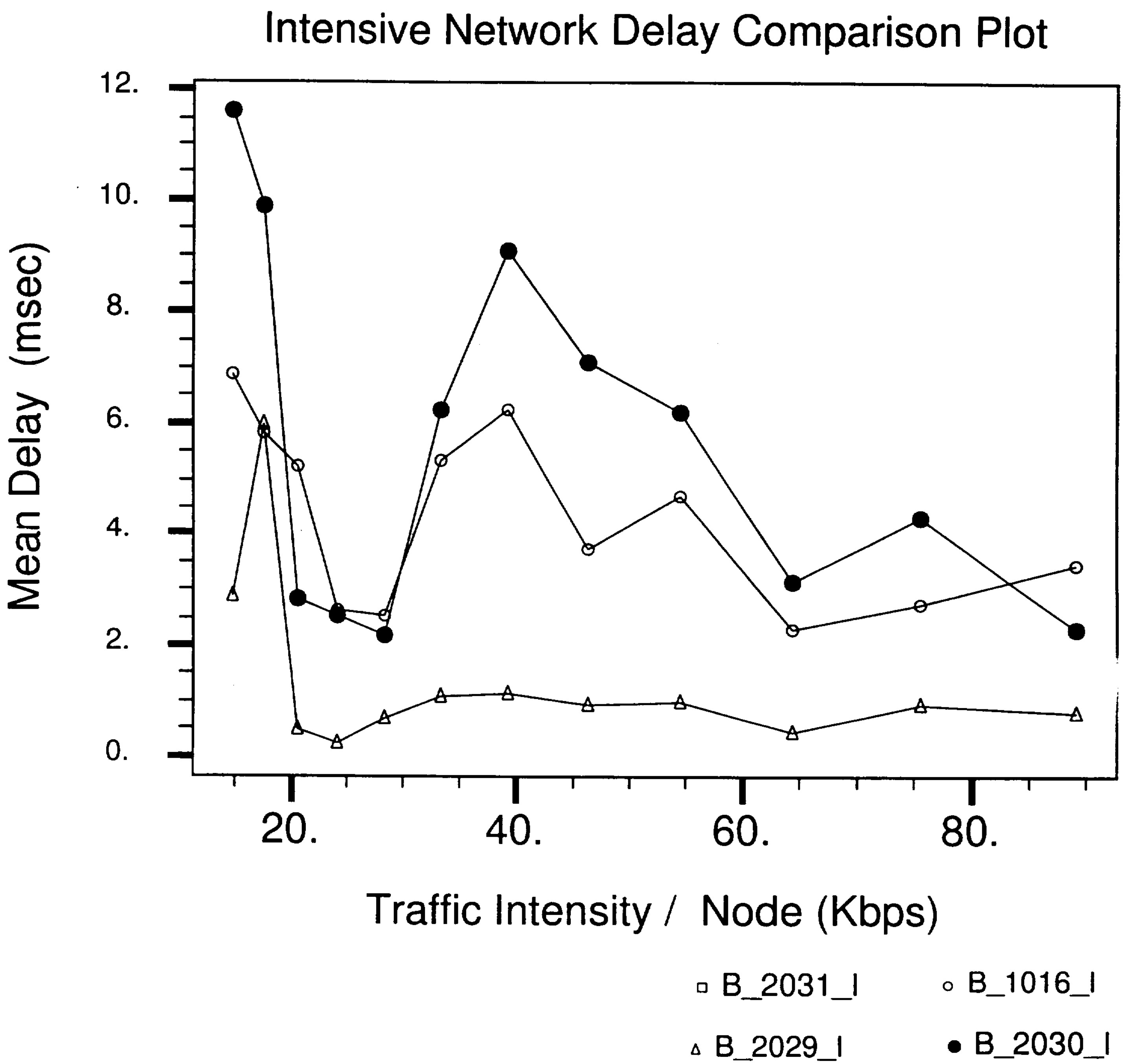


Figure 4.15 Intensive network delay plot for simulation time of 5 seconds

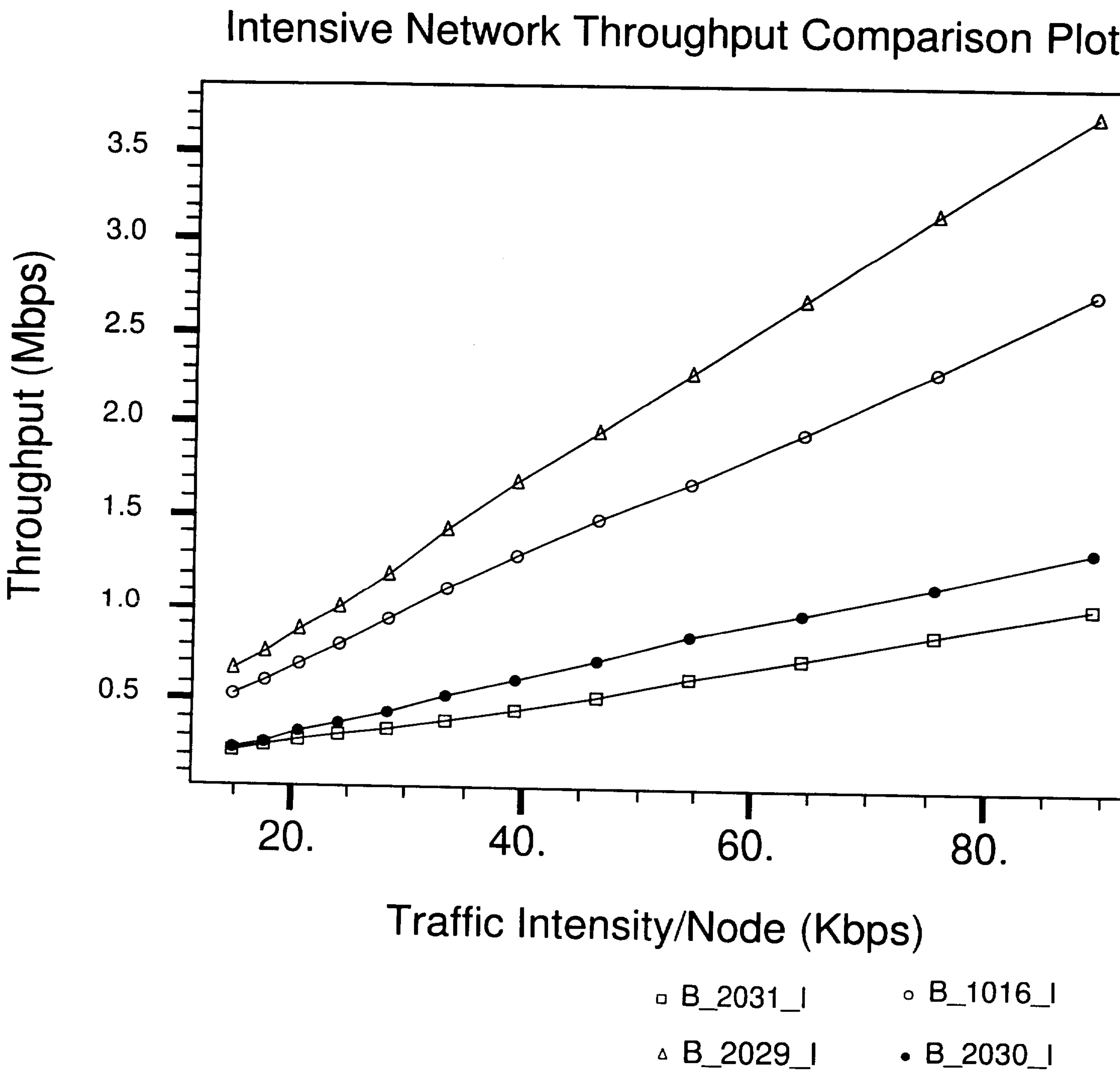


Figure 4.16 Intensive network throughput plot for simulation time of 5 seconds

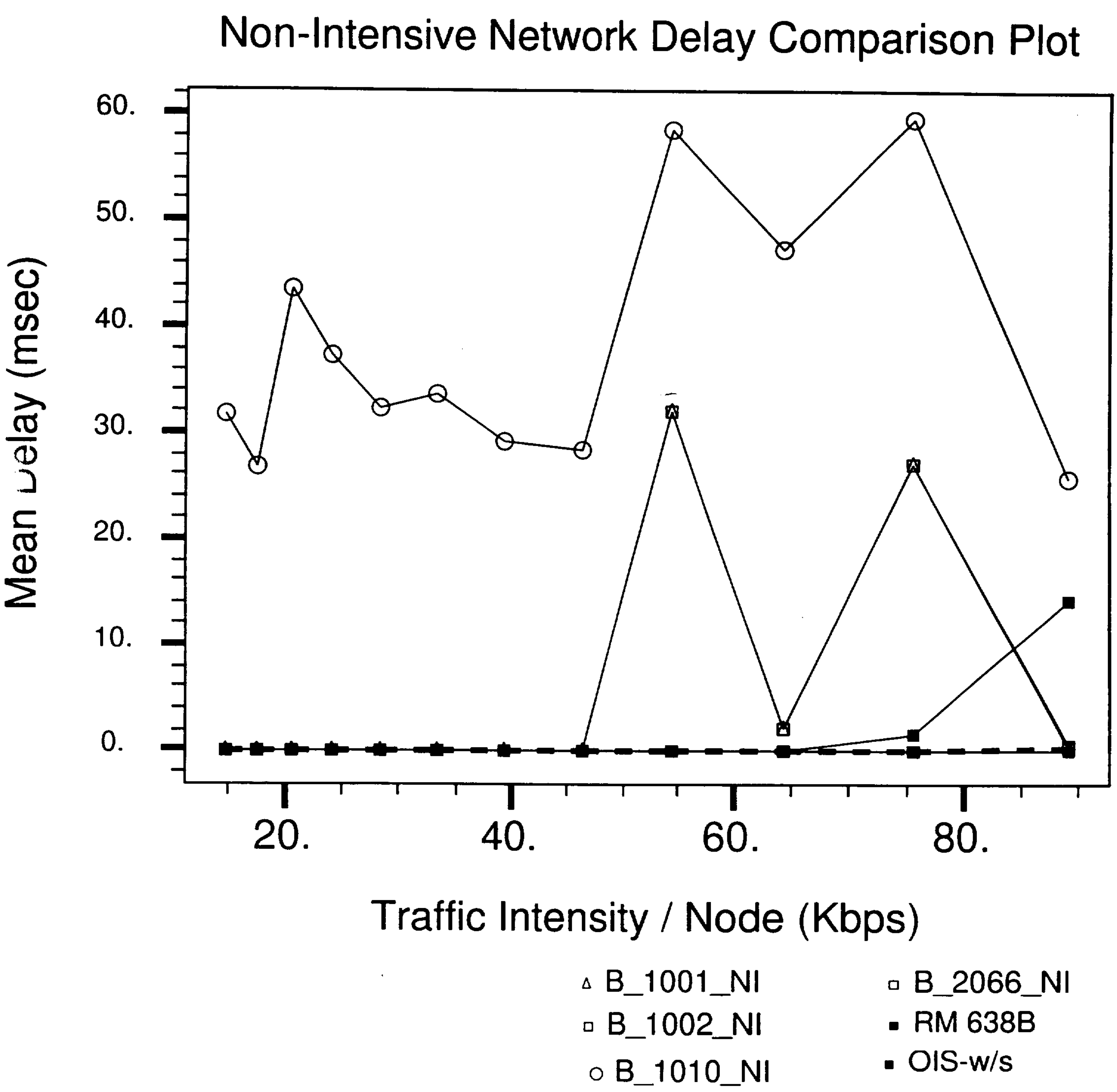


Figure 4.17 Non–Intensive network delay plot for simulation time of 5 seconds

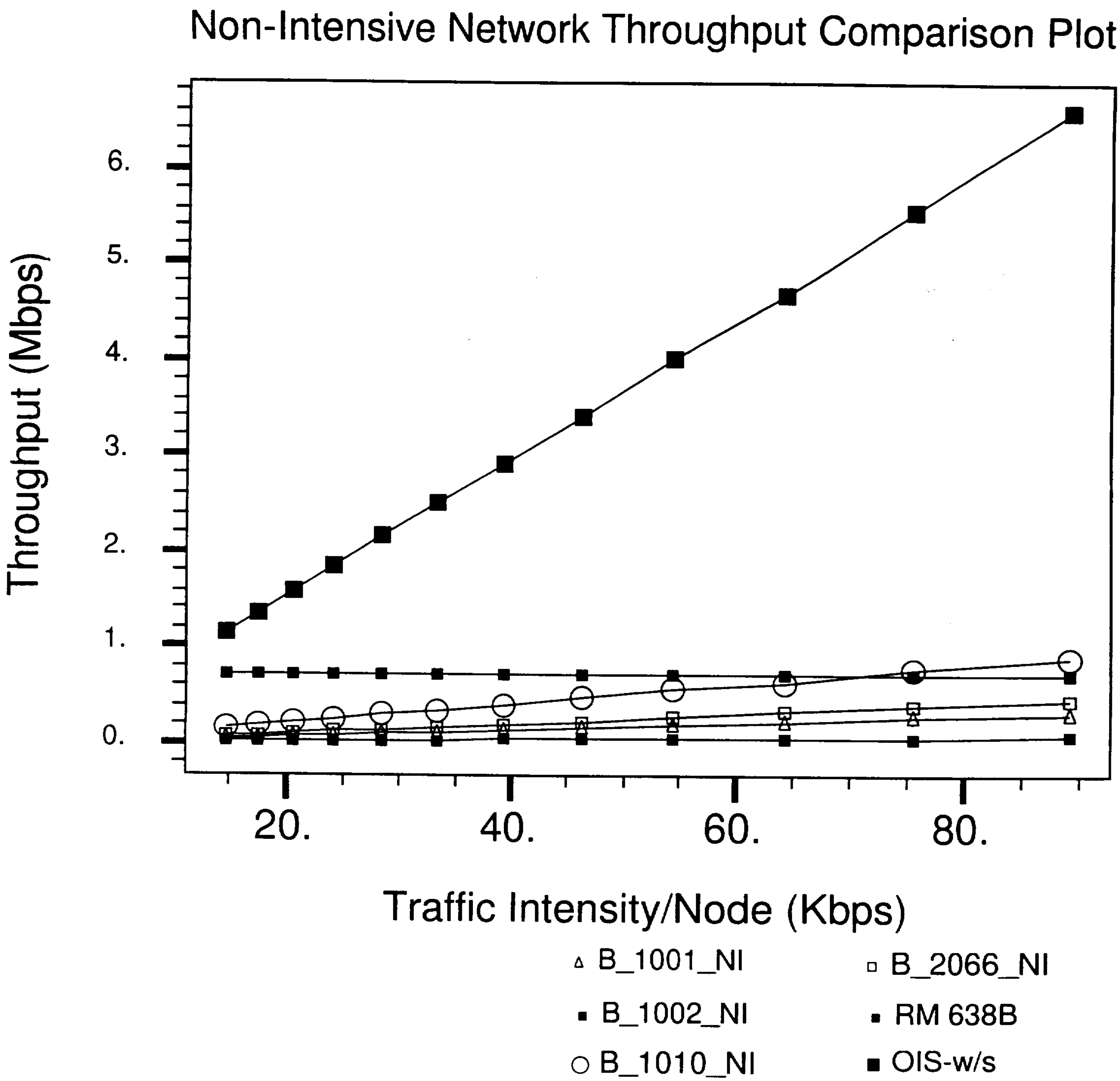


Figure 4.18 Non–Intensive network throughput plot for simulation time of 5 seconds

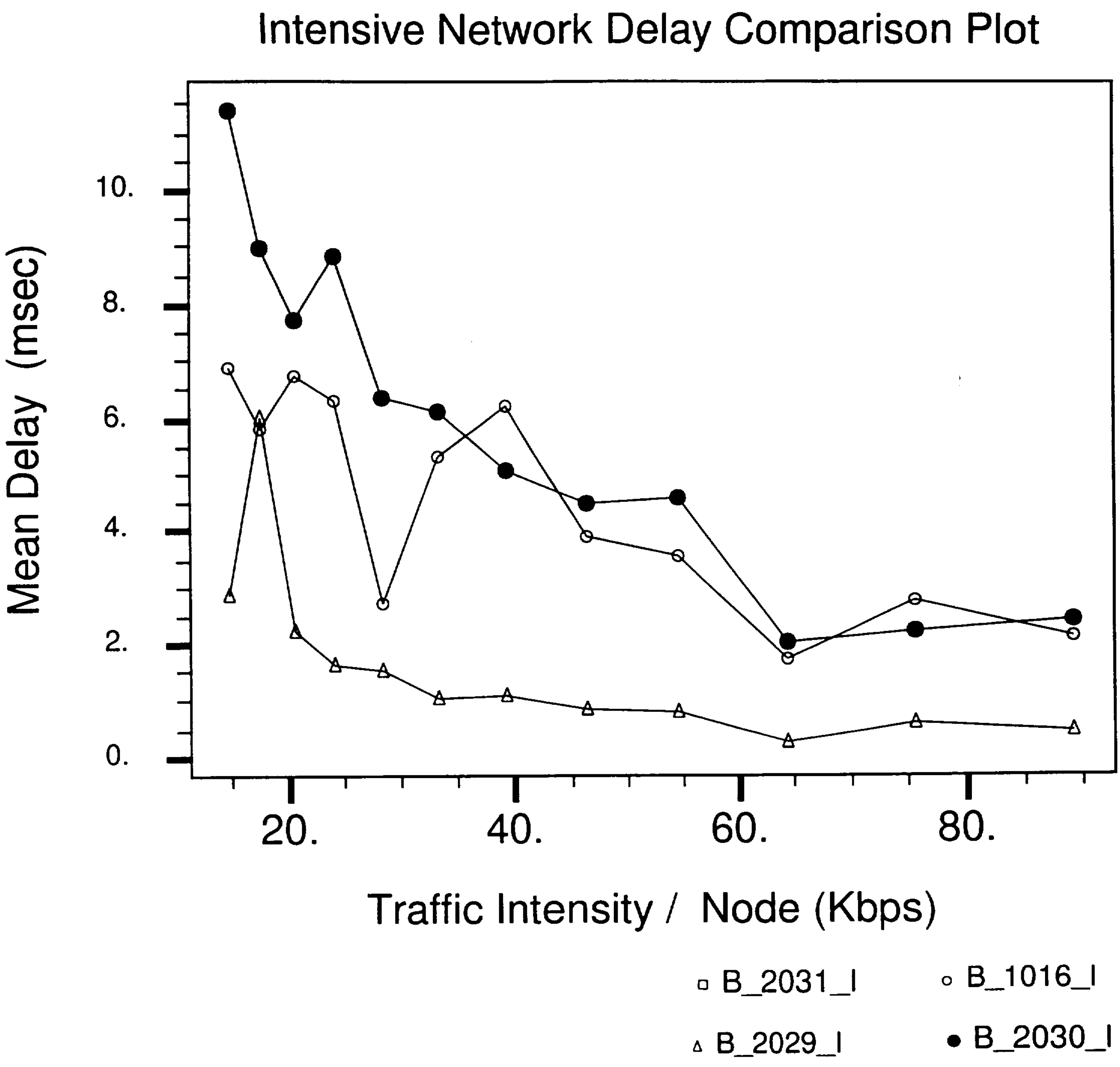


Figure 4.19 Intensive network delay plot for simulation time of 5 seconds without the BIS devices

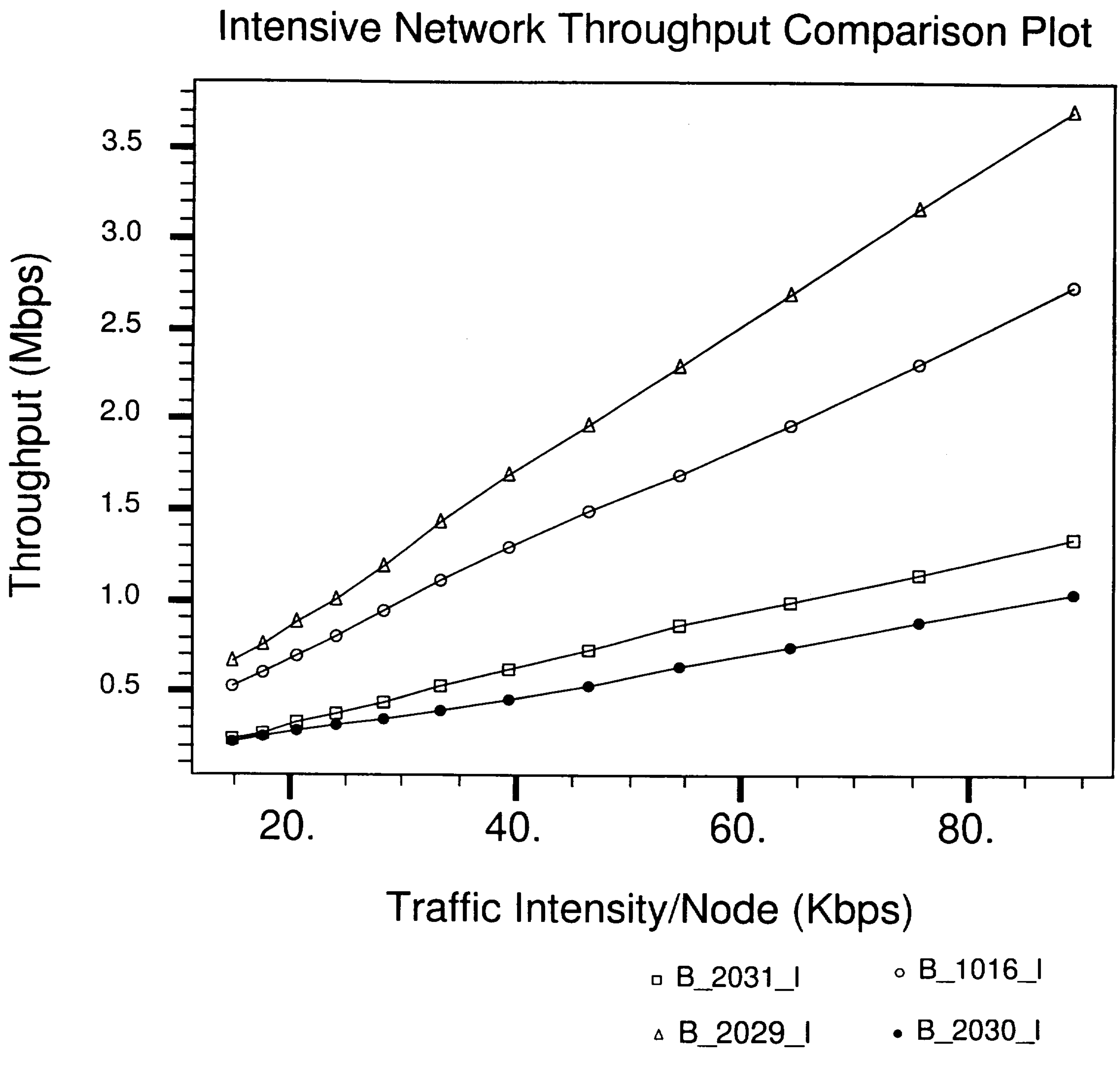


Figure 4.20 Intensive network throughput plot for simulation time of 5 seconds without the BIS devices

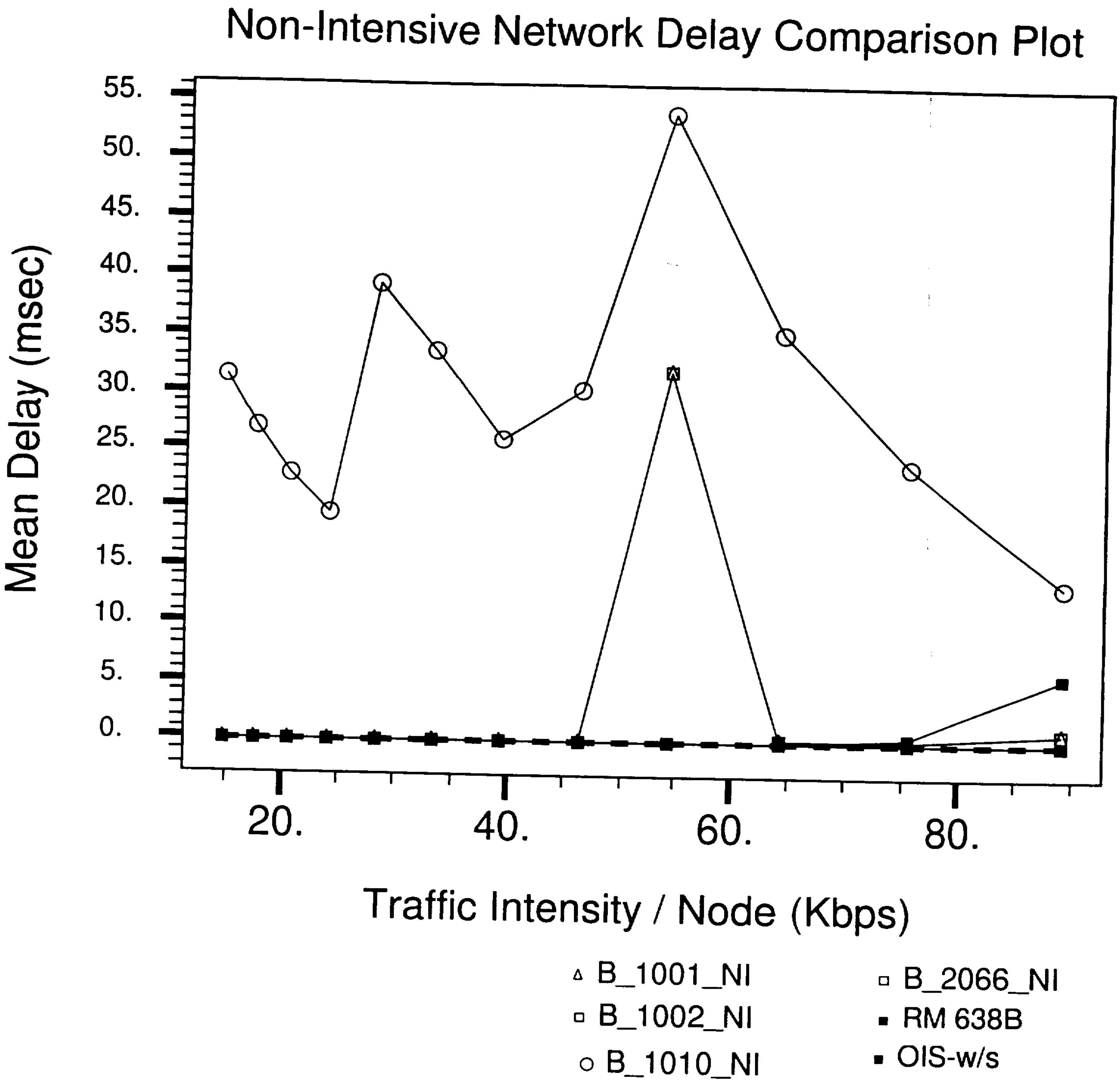


Figure 4.21 Non–Intensive network delay plot for simulation time of 5 seconds without the BIS devices

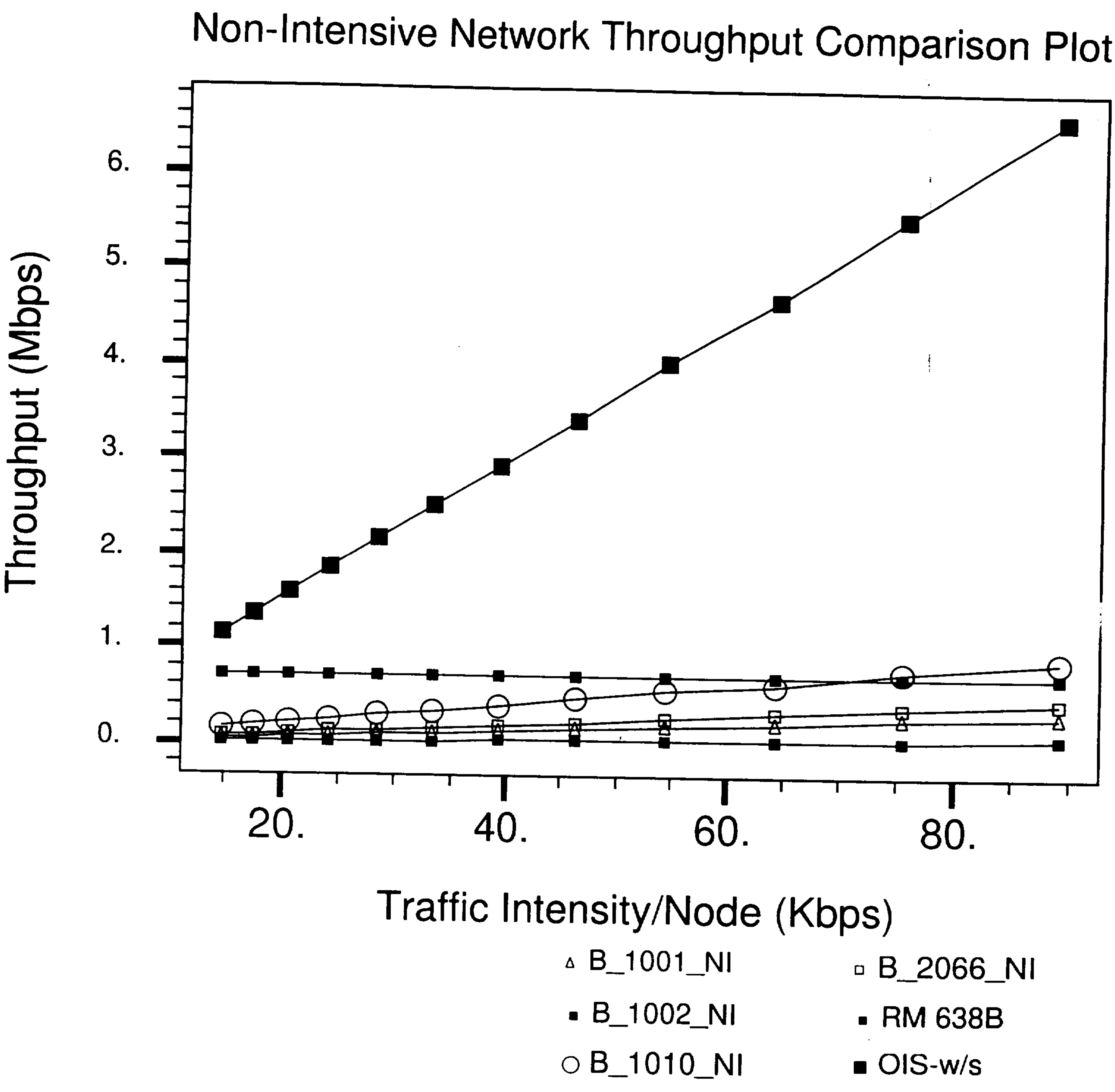


Figure 4.22 Non–Intensive network throughput plot for simulation time of 5 seconds without the BIS devices

## 4.6 Analysis of the Results

The mean delay per packet versus the offered traffic intensity plots obtained for the modified network are similar to that of the previous network except for the maximum value of the delay. The curves in the throughput versus the offered traffic intensity plots show that the throughput increases linearly with the offered traffic intensity per node, similar to that of the previous network.

The major differences between the plots for the new network and that of the previous network are as follows:

- There is a significant increase in the maximum delay value for the BIS sub–networks. This change can be attributed to moving the 73 OIS workstations from the OIS hub to the BIS hub.
- The mean delay values for the OIS intensive sub–networks has decreased. This is because one of the ASCs is moved from B_1000 to B_2029 and thus a lot of workcell traffic is diverted from B_1000.
- The randomness in the delay plots for the intensive and non–intensive sub–networks has been reduced to a great extent. The traffic between one of the ASCs and its workcells has been removed from the FDDI backbone. This change reduces the amount of traffic flowing across the backbone, and as a result, the plot of the delay curve is smoothed out.
- By comparing the mean delay and throughput plots with and without the BIS network attached, it can be seen that no significant change occurred in either the delay or throughput values. Thus it can be said that the BIS network has no major effect on the OIS network.

### 4.7 Conclusions

This chapter explains the ASRM network as of August 10, 1993 and compares the results from simulating this new network model with those of the previous model. Moving the 73 OIS workstations from the OIS hub to the BIS hub and moving one of the ASCs from B_1000 to B_2029 made a positive change in the network performance. The mean delay of the OIS intensive sub–networks has decreased. The randomness in the delay plots for the intensive and non–intensive networks has been reduced giving an indication that the effect of the buffer capacity of the bridges on the network has decreased. Also it was observed that the BIS network has no major effect on the OIS network. From these changes it can be said that more peer–to–peer communication will reduce the heterogeneity of the traffic flow across the network and prevent the traffic congestion at different junctions of network.

# APPENDIX

## A. Ravi's Thesis

# ANALYSIS OF THE DATA COMMUNICATION NETWORK AT THE ADVANCED SOLID ROCKET MOTOR FACILITY

By

Ravindra P. Nirgudkar

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in the Department of Electrical and Computer Engineering

Mississippi State, Mississippi
December 1993

ANALYSIS OF THE DATA COMMUNICATION NETWORK
AT THE ADVANCED SOLID ROCKET MOTOR
FACILITY

By

Ravindra P. Nirgudkar

Approved:

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Associate Professor of Electrical and
Computer Engineering
(Major Professor)

Franklin M. Ingels
Professor of Electrical and
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(Graduate Coordinator)

Jimmy D. Akers
Professor of Electrical and
Computer Engineering
(Committee Member)

Wayne D. Smith
Associate Professor of
Computer Science
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Robert Altenkirch
Dean of the College of Engineering

Richard D. Koshel
Dean of the Graduate School

Name: Ravindra Prabhakar Nirgudkar

Date of Degree:

Institution: Mississippi State University

Major Field: Electrical Engineering

Major Professor: Dr. Robert J. Moorhead

Title of Study: ANALYSIS OF THE DATA COMMUNICATION NETWORK AT THE ADVANCED SOLID ROCKET MOTOR FACILITY

Pages in Study: 106

Candidate for Degree of Master of Science

This thesis describes analyzes the communication network for the NASA Advanced Solid Rocket Motor (ASRM) facility under construction at Yellow Creek near Iuka, Mississippi. Manufacturing, testing, and operations will be performed in various buildings scattered over a 1800 acre site. These buildings will be interconnected through a Local Area Network (LAN), which will contain one logical Fiber Distributed Data Interface (FDDI) ring acting as a backbone for the whole complex. The network will contain approximately 700 workstations, 22 workcells, and 3 VAX clusters interconnected via Ethernet and FDDI. The different devices will produce appreciably different traffic patterns, each pattern will be highly variable, and some patterns will be very bursty. Most traffic will be between the VAX clusters and the other devices. Comdisco's Block Oriented Network Simulator (BONeS) will be used for network simulation. The primary evaluation parameters used to judge the expected network performance will be throughput and delay.

ACKNOWLEDGMENTS

Sincere appreciation is extended to Dr. Robert J. Moorhead for serving as major advisor during my graduate studies and for providing guidance, facilities, and support for the research described in this thesis.

Sincere gratitude is expressed to Dr. Wayne D. Smith for his timely suggestions and constant encouragement.

Appreciation is expressed to the Department of Electrical and Computer Engineering for the computer facilities.

Financial aid and support for this study were provided by the National Aeronautics and Space Administration under Grant NAG8-866.

Finally, a very special expression of appreciation is extended to my parents. Without their encouragement and understanding this endeavor would not have been possible.

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# CHAPTER 1.0

# INTRODUCTION

The Advanced Solid Rocket Motor (ASRM) facility at Yellow Creek near Iuka, Mississippi is part of a National Aeronautics and Space Administration (NASA) program to substantially improve the flight safety, reliability, productivity, and performance of the space shuttle's solid rocket motors. The ASRM will be a replacement for the current space shuttle Redesigned Solid Rocket Motor (RSRM).

The facility will be government–owned but contractor–operated. Lockheed Missiles and Space Company Inc., (LMSC) is the prime contractor. The operation of the facility will be directed by the subcontractor Aerojet ASRM division (AAD); RUST International Corporation (RUST) is responsible for the engineering and construction of the facility [1].

## 1.1 ASRM System Configuration

The operations at the ASRM site will be performed in different buildings scattered over a large area. These buildings will be inter–connected through a Local Area Network (LAN). The buildings can be classified as Manufacturing Intensive buildings and Manufacturing Non–Intensive buildings, depending on the type of operation performed within the building. There will be four Manufacturing Intensive hubs and four Manufacturing Non–Intensive hubs connecting the respective buildings to the Main Computing Center in Building 1000 (B_1000). All the workcells will be connected to the nearest Manufacturing Intensive Hub.

Each Manufacturing Intensive hub will communicate with either the Operational Information System (OIS) or an Area Supervisory Computer (ASC) via a Fiber Distributed Data Interface (FDDI) protocol over an optical fiber link. The workstations will interact with the OIS, while the workcell's data will be routed to the ASCs. Each Manufacturing Non–Intensive hub will communicate with the Business Information System (BIS) by Ethernet protocol over an optical fiber link.

The two VAX computers in the OIS VAX cluster can communicate directly with each other. The BIS on the other hand is a single entity. All the printer jobs throughout the campus except those from B_1000 will be routed through the Gandalf terminal server by the BIS.

For all the data transfer, the required routing, security, and flexibility will be provided by the Cabletron Multi Media Access Centers (MMACs) which will be used throughout the campus. The overall network logically forms one large FDDI ring although physically it is a combination of various point–to–point connections.

## 1.2 Summary of the Forthcoming Chapters

The main aim of the thesis is to present the overall communication network structure for the ASRM facility. The thesis is composed of chapters discussing the ASRM communication network structure, the BONeS simulation of the ASRM network, and an analysis of the simulation results.

The chapter on 'ASRM Communication Network Structure' concentrates on the network connectivity, cabling, and the different protocols used. This chapter also explains the flow of data in the network.

The chapter on 'BONeS Modeling' gives an overview of the BONeS simulator. This chapter also describes the different BONeS models developed to simulate the ASRM environment and the different probes and the iteration settings used.

The 'Analysis and Results' chapter comments on the network expectations and the network evaluation parameters. The chapter also summarizes the various plots of Mean Delay and Throughput versus Traffic Intensity.

The 'Conclusion' chapter at the end of the thesis summarizes the different findings from the simulation results. The chapter also makes an attempt to validate the simulation model and verify the simulation results. A few recommendations for further study is also provided at the end of that chapter.

## 1.3 Research Objective

The main objective of the research was to simulate and analyze the network to determine its performance under different conditions. Comdisco's Block Oriented Network Simulator (BONeS) was used for network simulation. The performance of the network with the given topology and protocols can be evaluated using BONeS. The two primary evaluation parameters used to judge the network performance were the throughput and the delay. The aim of the simulations was to estimate the loading of the OIS, the BIS, the ASCs, and the network links due to the traffic generated by the workstations and the workcells over the entire site.

# CHAPTER 2.0

# ASRM COMMUNICATION NETWORK STRUCTURE

## 2.1 Main Computing Center (Building 1000)

### 2.1.1 Purpose of the Main Computing Center

Building 1000 (B_1000) will provide an efficient means to plan, control, and document the manufacturing of solid rocket motors for the ASRM project. All the workstations and the workcells communicate only with the OIS, the BIS, and the ASCs in B_1000; there is no peer–to–peer communication required. B_1000 also provides a link between the business functions and the manufacturing functions of the facility. The interconnection between the devices in B_1000 is shown in Figure 2.1.

B_1000 will have a Gandalf terminal server. The Gandalf terminal server is a large terminal server with a multitude of RS–232 to Ethernet ports. The Gandalf can support 12 separate Ethernet channels. It will be the only terminal server throughout the campus.

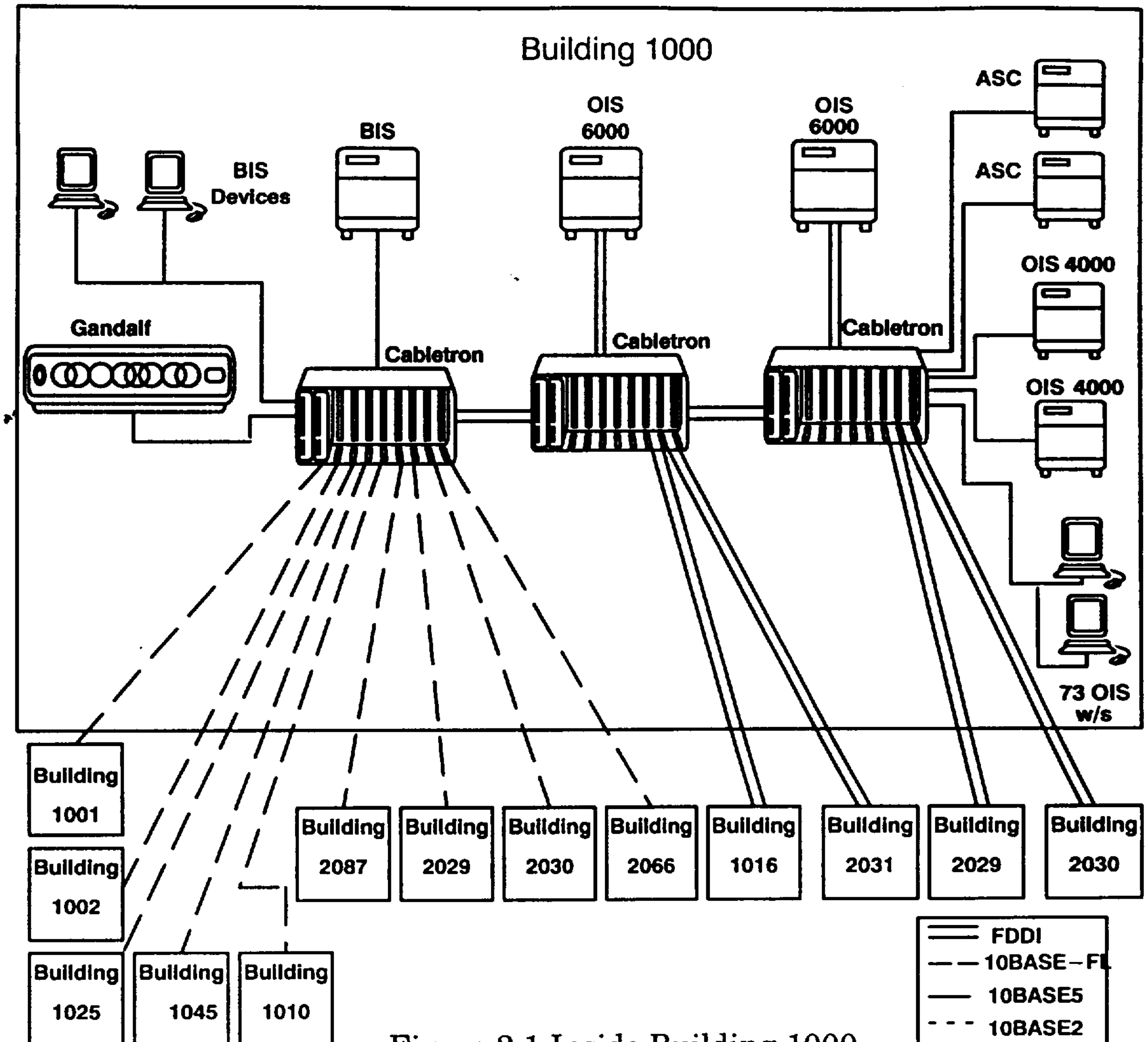


Figure 2.1 Inside Building 1000

<u>2.1.2 BIS Network</u>

The BIS will be a VAX cluster consisting of one VAX 6310 and two VAX 6420 computers. The BIS will be connected to its Cabletron hub by thick–wire coaxial with 10BASE5 protocol. The main functions of the BIS network will be routing to / from the Gandalf terminal server and serving most of the devices inside B_1000.

The BIS devices includes 32 printers, 25 CAD workstations, and 400 Macintosh computers connected to the BIS hub by 10BASET; 50 PCs connected to the BIS hub by 10BASET; 31 Engineering workstations on 10BASE2; and 289 dumb terminals connected via Asynchronous Data Interface (ADI) to the Gandalf. The connections of the BIS devices are as shown in Figure 2.2.

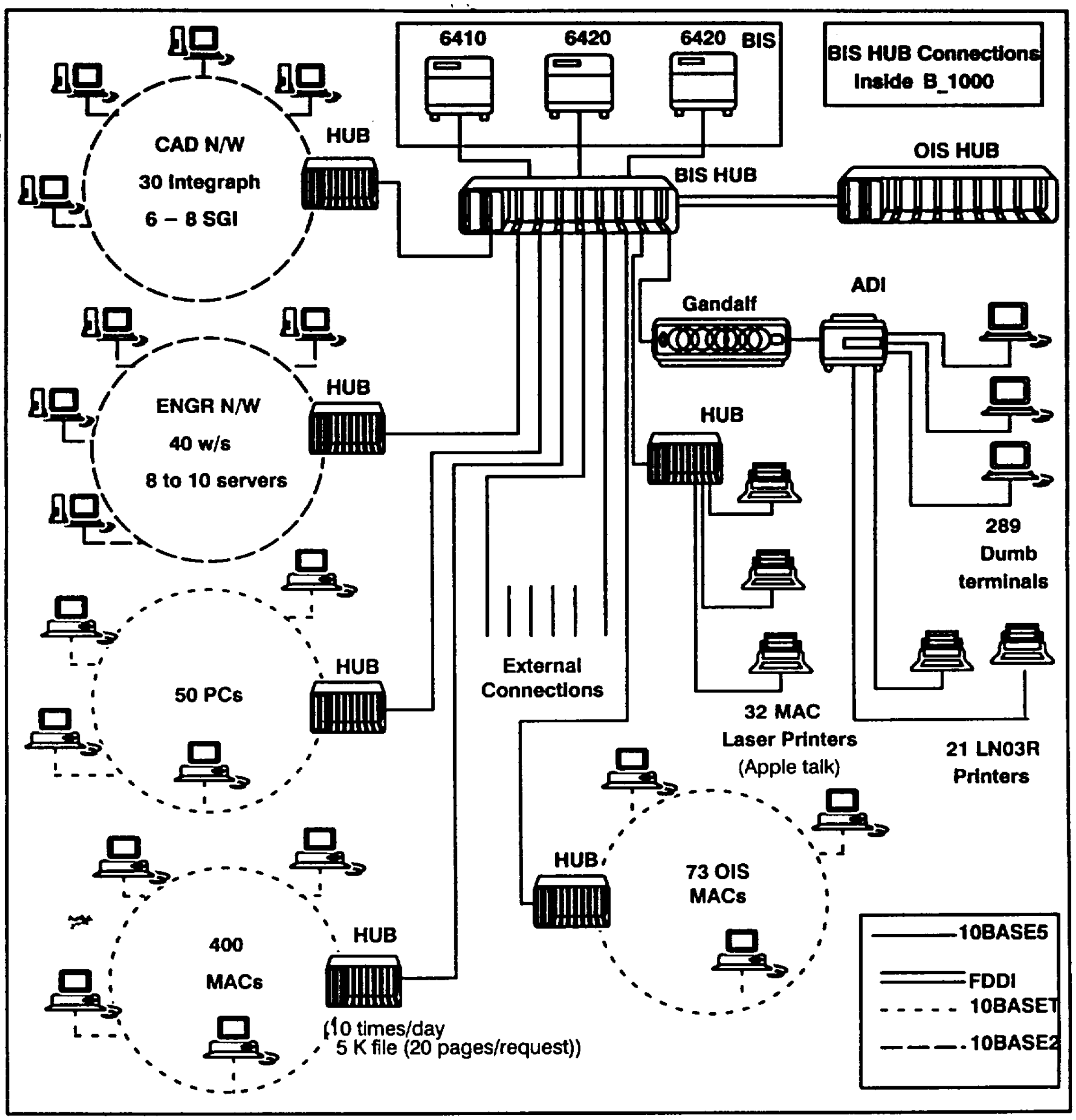


Figure 2.2 BIS Hub Connections

The BIS hub and the OIS hubs will be connected to provide a path for the printer jobs from the Manufacturing Intensive buildings to the Gandalf terminal server and subsequently to the printers. Except for this function and the traffic from the 73 OIS workstations, all the BIS traffic will be independent of the OIS traffic.

### 2.1.3 OIS Network

The OIS will be a VAX cluster consisting of two VAX 6000 computers, each with one FDDI adapter. In addition to this OIS VAX cluster, there will be two VAX 4000 computers, each with one Ethernet adapter. Each of the OIS VAX 6000 computers will be connected to the Cabletron hub by optical fiber using the FDDI protocol, while each of the OIS VAX 4000 computers will be connected to one of the Cabletron hubs by thick wire coaxial cable using the 10BASE5 protocol.

The main operations of the OIS will be to provide efficient means to plan, control, and provide data collection using commercial software packages[2] and to download and upload information to each ASC, which will serve a group of workcells.

### 2.1.4 ASC Network

Each of the ASCs will be a VAX 4400 with an Ethernet adapter. The ASCs will be connected to the Cabletron hub by thick wire coaxial cable using the 10BASE5 protocol.

The ASC is a real–time device which handles the Application Program Interfaces (APIs). The ASC has similar functionality to the OIS. The ASC will control and manage a set of workcells. The ASCs will communicate with the OIS occasionally with a large block of data, rather than communicating continuously, which would slow down the OIS operation. Also if the OIS goes down, the ASC will keep the network alive and log the data.

2.1.5 Cabletron Devices

The OIS, the BIS, the ASCs, and the Gandalf terminal server in B_1000 will be connected to the outside network complex by the Cabletron Multi Media Access Centers (MMACs), the intelligent hubs. In addition B_1000 will have nine more Cabletron hubs distributed in two switch rooms (viz. 507 and 638) for the BIS devices in B_1000. The Cabletron hubs provide necessary security, routing, and redundancy [24].

The Cabletron devices provide network redundancy in two forms. The first method is to ensure that all data connections have two back–up paths. This method allows critical servers, nodes, or backbone to be backed–up with multiple data paths from one or more MMACs. In event of a data path failure, back–up paths take over. This feature is useful in connecting the manufacturing intensive hubs to B_1000 at the ASRM site. The second method of redundancy built into the MMAC is its load sharing / redundant power supplies.

The MMACs chassis are modular, allowing one to hot swap media boards and power supplies. This feature reduces the downtime, as units can be serviced quickly without special tools. At the ASRM site all the MMAC devices will be MMAC–8FNB allowing for connection of up to seven Media Interface Modules (MIM). The first slot in the MMAC will be the EMME multichannel management / bridge module. The different MIMs used in the network at the ASRM are listed in Table 2.1.

Table 2.1 Cabletron MIMs used at ASRM

| Name of the Card | Type of the Card | Protocol | Number of ports | Comments |
| --- | --- | --- | --- | --- |
| EMME | Ethernet Bridge | Ethernet | 4 ports | Used as a management module in all the MMACS |
| FDMMIM | FDDI to Ethernet Bridge | — | 8 ports | Connects 10 Mbps Ethernet to 100 Mbps FDDI |
| MT8–MIM | DELNI Card | — | 8 ports | AUI Transceiver |
| FOR-MIM–22 | 10BASE–FL Card | Ethernet | 12 ports | Provides connectivity for 12 Ethernet channels |
| TPRMIM–36 | 10BASE–T Card | Ethernet | 24 ports | Provides Connectivity for 24 Ethernet Channels |
| CXRMIM | DEMPR Card | Ethernet | 12 ports | Provides Connectivity for 12 Ethernet Channels |
| GX–M | GatorStar Card | LocalTalk | 24 ports | Integrates 24 port LocalTalk repeater with a LocalTalk to Ethernet router |
| FDMMIM–04 | FDDI Concentrator | FDDI | 4 ports | Provides 4 concentrator ports for FDDI connections |

## 2.2 Network Cabling at the ASRM Site

### 2.2.1 Transmission Media

The transmission medium is the physical path between transmitter and receiver in a data transmission system. The characteristics and quality of data transmission are determined both by the nature of the signal and the nature of the medium. Table 2.2 gives typical characteristics for guided media, including the total data rate that the medium can support, the bandwidth the medium can transmit, and the minimum repeater spacing for digital transmission [15].

Table 2.2 Transmission Media Characteristics

| Transmission Medium | Total Data Rate | Bandwidth | Repeater Spacing |
|---|---|---|---|
| Twisted Pair | 4 Mbps | 250 KHz | 2 – 10 Km |
| Coaxial Cable | 500 Mbps | 350 MHz | 1 – 10 Km |
| Optical Fiber | 2000 Mbps | 2000 MHz | 10 – 100 Km |

### 2.2.2 Outdoor Cabling at the ASRM Site

All the outdoor cabling will be optical fiber. All optical fiber will be 62.5 / 125 micron multimode optical fiber. The outdoor cabling will support the FDDI standards for installation methodology and signal loss. There will be no outside splicing of the fiber, and all the indoor splicing will be done by fusion.

The manufacturing intensive buildings will have two FDDI data paths from B_1000 with automatic switchover. One data path will be buried, while the other will be aerial. Buildings 1016, 2029, 2030, and 2031 are the manufacturing intensive buildings; each will have a hub directly connected to a hub in B_1000. Buildings 2060 and 2076 will be connected to the hub in building 2029. Each hub will receive two pairs of fibers from the outside cable plant. All workstations and workcell devices will receive two fibers each from the respective hubs.

All the manufacturing non–intensive buildings in the complex will receive two fibers for its hub via the outside cable plant. All the workstations inside the buildings will get two fibers each from the respective hub.

Every FDDI hub will have at least three redundant paths, viz. Channel A and Channel B of FDDI and a 10BASE–FL backup. Also every FDDI hub will have two redundant dual rings.

### 2.2.3 Indoor Cabling at the ASRM Site

For the indoor cabling in the manufacturing intensive buildings, the 10BASE–FL protocol will be used, mainly because it allows lower light levels and 16 redundant data paths. In addition, the Cabletron devices support the 10BASE–FL protocol [24].

### 2.2.4 Telephone Cabling

The telephone system at ASRM Iuka is being built around an Intecom S/80 switch. The only overlap in the voice and data networks is between the Gandalf terminal server and the RS–232 devices it serves. The Intecom system will be used as the network for communicating serial information between the aforementioned devices. The RS–232 devices consist of printers and some workcells.

### 2.2.5 Physical Distances

Table 2.3 gives the physical distance of all the buildings from the nearest hub. Table 2.4 gives the physical distance of all the hubs from B_1000.

Table 2.3 Distances of each building from the nearest hub

| Building No. | Building Name | No. of worksta-tions | No. of work-cells | Link | Near-est hub | Dis-tance from hub(ft) |
|---|---|---|---|---|---|---|
| 1000 | Engineering / Computer | 73 | 00 | — | 1000 | — |
| 1001 | Security and Medical | 03 | 00 | Link #4 | 1000 | 1500 |
| 1010 | Central Warehouse | 10 | 00 | Link #4 | 1000 | 600 |
| 1012 / 2087 | Warehouse 'A' | 14 | 00 | Link #7 | 1012 | — |
| 1016 | Case Prep. and Refurbishment | 27 | 16 | Link #3 | 1016 | — |
| 1022 | Chemical Storage | 01 | 00 | Link #4 | 1000 | 2600 |
| 1025 | Carpenters Shop | 01 | 00 | Link #4 | 1000 | 2400 |
| 1032 | Office | 03 | 00 | Link #5 | 2066 | 800 |
| 1045 | Training Center | 04 | 00 | Link #4 | 1000 | 1400 |
| 2028 | Tool Clean / Core Prep. | 08 | 00 | Link #1 | 2029 | 2600 |
| 2029 | Remote Control Room | 12 | 01 | Link #1 | 2029 | — |
| 2030 | Non Destructive Evaluation Facility | 03 | 02 | Link #6 | 2030 | — |
| 2031 | Final Assembly | 15 | 00 | Link #2 | 2031 | — |
| 2042 | Main Motor Storage | 04 | 00 | Link #6 | 2030 | 8650 |

Table 2.3 (continued)

| Building No. | Building Name | No. of worksta-tions | No. of work-cells | Link | Near-est hub | Dis-tance from hub(ft) |
|---|---|---|---|---|---|---|
| 2070 | Sample Preparation | 01 | 00 | Link #5 | 2066 | 1450 |
| 2060 | Small Scale Propellant Proc. | 04 | 02 | Link #1 | 2029 | 2250 |
| 2066 | Quality Assurance Lab. | 05 | 00 | Link #5 | 2066 | — |
| 2076 | Qualification Motor Facility | 04 | 01 | Link #1 | 2029 | 2550 |
| 2082 | HTPB Storage Tank Farm | 01 | 00 | Link #1 | 2029 | 850 |
| 3003 | Deload – Open area (no building) | 00 | 01 | Link #6 | 2030 | 7050 |
| 3005 | Control Building | 03 | 01 | Link #6 | 2030 | 5950 |
| 3010 | Incinerator System Building | 00 | 01 | Link #6 | 2030 | 4950 |
| 3011 | Feed Prep. Facility | 01 | 01 | Link #6 | 2030 | 6600 |
| 4001 | Shipping Dock | 01 | 00 | Link #6 | 2030 | 9700 |
| | TOTAL | 184 | 26 | | | |

Table 2.4 Distances of each hub from Building 1000

| Link | Distance (feet) | Number of workstations on the link | Number of workcells on the link | Type of the link |
|---|---|---|---|---|
| Link # 1 : (2029) | 6700 | 29 | 04 | Intensive and Non–Intensive |
| Link # 2 : (2031) | 4650 | 15 | 00 | Intensive |
| Link # 3 : (1016) | 1450 | 27 | 16 | Intensive |
| Link # 4 : (1000) | 00 | (19+73) + BIS devices | 00 | Non–Intensive |
| Link # 5 : (2066) | 3550 | 09 | 00 | Non–Intensive |
| Link # 6 : (2030) | 5000 | 12 | 06 | Intensive and Non–Intensive |
| Link # 7 : (1012) | 950 | 14 | 00 | Non–Intensive |

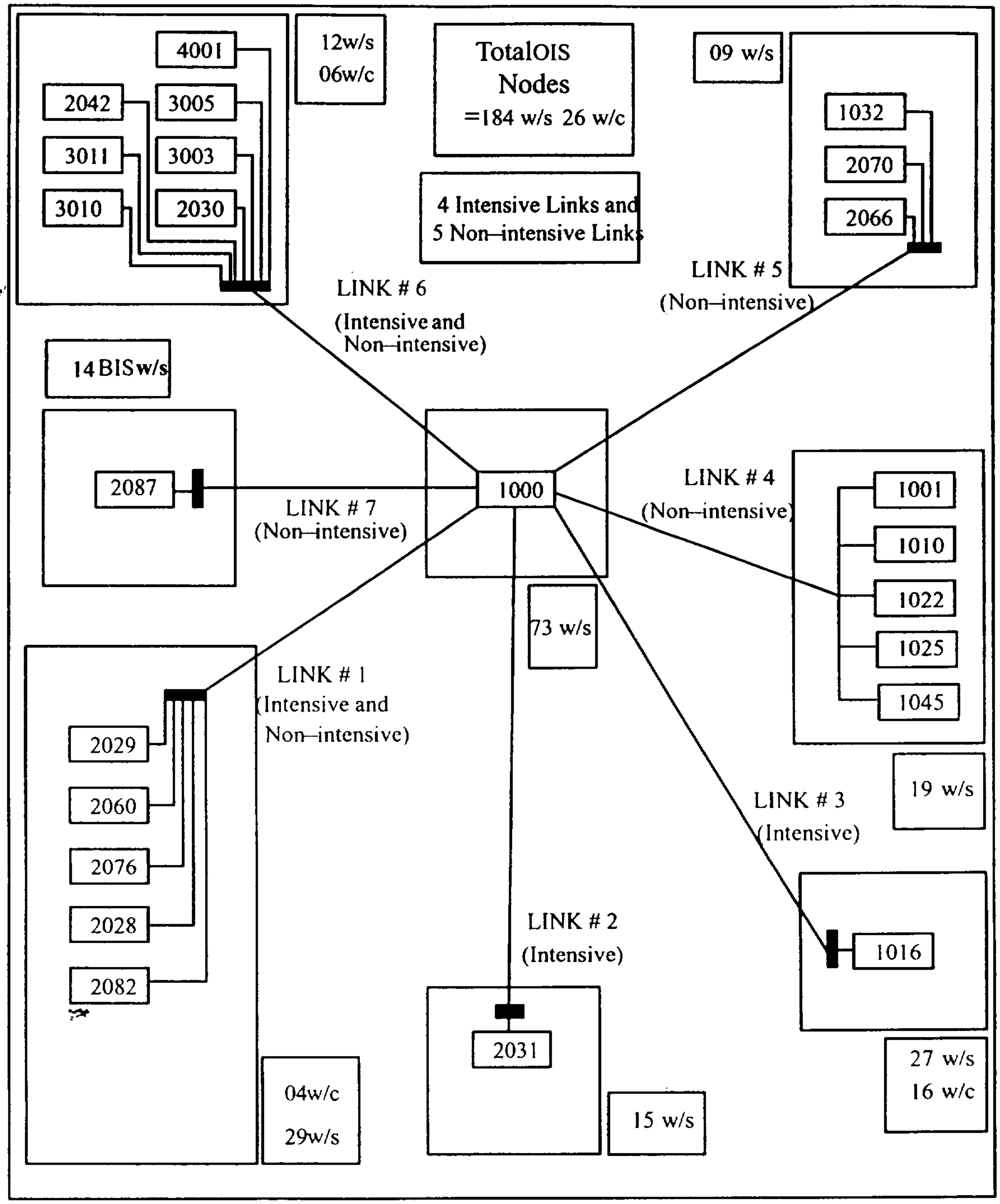


Figure 2.3 Building–to–Building External Connections

## 2.3 Protocols used at the ASRM Site

### 2.3.1 Standard Protocols

For two entities to successfully communicate over a network, they must conform to some mutually acceptable set of coventions referred to as a protocol. A protocol may be defined as a set of rules governing the exchange of data between two entities. The Institute of Electrical and Electronic Engineers (IEEE) has established different committees to develop standards for LANs viz. 802.2 Logical Link Control (LLC), 802.3 Carrier Sense Multiple Access Collision Detect (CSMA/CD), 802.4 Token Bus, and 802.5 Token Ring. The American National Standards Institute (ANSI) has developed a specification for LANs using optical fiber. The standard is called Fiber Distributed Data Interface (FDDI) and was written by ANSI committee X3T9.5 [15].

### 2.3.2 Protocols used at the ASRM Site

For the data communication network at the ASRM site, two protocols are specified: FDDI and CSMA/CD. All the manufacturing intensive buildings are connected to B_1000 by links with FDDI protocol, and all the manufacturing non-intensive buildings are connected to B_1000 by links with 10BASE–FL protocol (i.e. CSMA/CD on optical fiber). The protocol inside both the manufacturing intensive and non-intensive buildings is 10BASE–FL. In B_1000 the 25 CAD workstations, 400 Macintosh computers, and 50 PCs use 10BASET, the 31 Engineering workstations use 10BASE2, and the 289 dumb terminals use RS–232. The 289 dumb terminal traffic is carried over intecom S–80 switch and hence they can be considered part of the telephone network.

2.3.3 FDDI Protocol

The FDDI protocol operates on an optical fiber channel at 100 Mbps. Up to 1000 nodes can be placed on one optical fiber ring. The nodes can be spaced as far as 2 km apart and the ring circumference can be up to 200 km [14]. FDDI specifies a topology in which two independent, counterrotating optical fiber rings provide a overall bit rate of 200 Mbps, with each channel operating at 100 Mbps.

In Figure 2.4 some devices (A type) are attached to both inner and outer rings, while other devices (B type) are attached to only one ring. This allows a user to designate those critical stations which need additional back–up and higher speeds as type A stations. The other, less important ones such as isolated workstations or low–priority terminals, can be attached as type B stations, at a lesser cost.

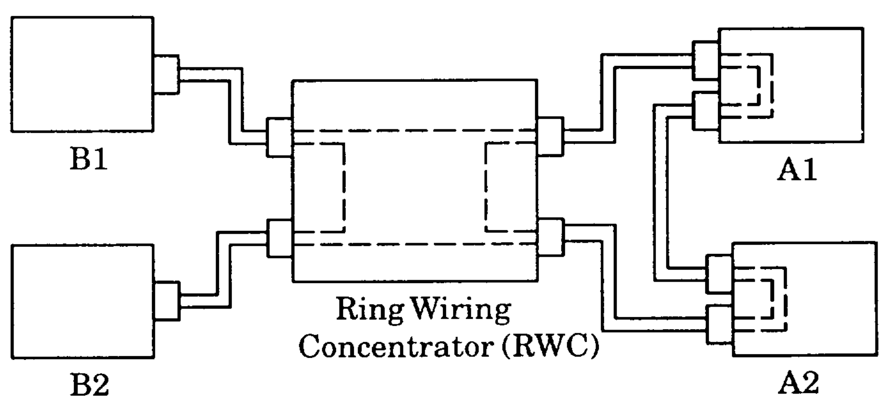


Figure 2.4 FDDI Topology

The Ring Wiring Concentrator (RWC) acts as a reconfiguration and concentration point for all optic wiring and data traffic. The connectors into the terminals and wiring concentrator are laser diodes which can drive the fiber at a rate of over 100 MHz. FDDI stipulates a standard optic light wave of 850 nanometers.

FDDI utilizes a 4B / 5B encoded signal at a rate of 125 Mbps. Encoded signals are grouped as data and linestates. Data signals contain a nibble (4–bits) of data encoded into a 5 bit symbol, hence the resulting data rate is 4 / 5 of the actual bit rate or 100 Mbps. Linestate signals are non–data 5 bit symbols that allow for a rudimentary communication protocol below the Medium Access Control (MAC) layer.

FDDI uses a multiple token passing protocol. The token circles the ring behind the last transmitted packet from a device. Any station wishing to transmit data seizes the token, removes the token, places the packet or packets on the ring, and then issues the new token directly behind the data stream.

### 2.3.4 CSMA/CD Protocol

CSMA / CD also referred to as Listen While Talk (LWT) is the most commonly used Medium Access Control (MAC) technique for bus / tree topologies. The original baseband version of this technique was developed and patented by XEROX.

In CSMA / CD many different stations are connected to a common bus. If two stations try to transmit at the same time then the packets will collide, at which point each station stops transmission and waits a random amount of time before trying to transmit again. If the packet from a station collides again, then the station waits a longer amount of time, determined by the random exponential backoff time for that station, before trying to transmit. The IEEE 802.3 CSMA / CD standard sends data in variable size frames commonly called packets with a minimum spacing of 9.6 microseconds.

For any hub, if there is activity (signal) on more than one input, a collision is assumed. A special signal called the collision presence signal is generated. This signal is generated and sent out as long as activity is still sensed on any of the input lines after a collision is detected. This signal is interpreted by every node as an occurrence of collision.

### 2.3.5 ASC to LSC Communication Protocol

The ASCs will be used to monitor and control the shop floor test equipment and the automated workcells.

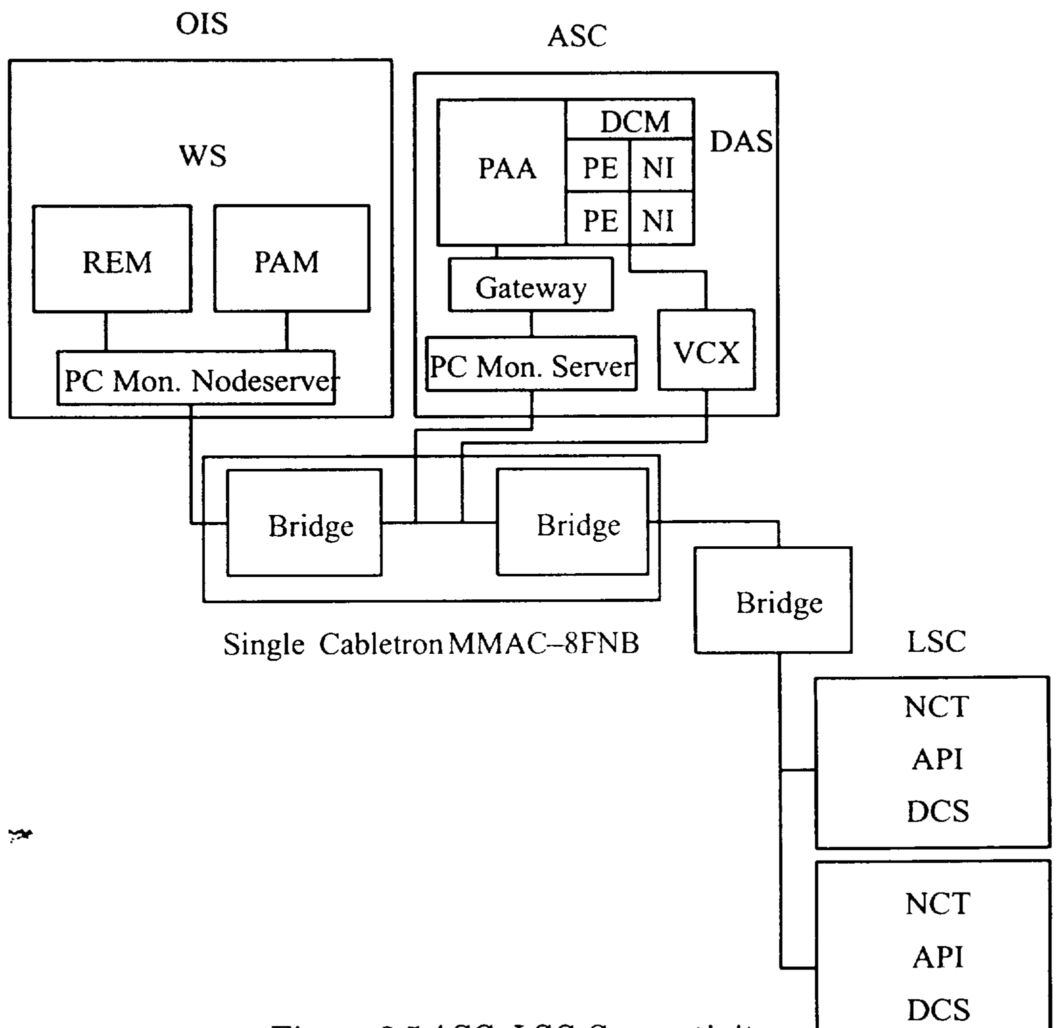


Figure 2.5 ASC–LSC Connectivity

At the Local Supervisory Computer (LSC) level, data from the workcell devices are collected by utilizing software provided by RUST International. Data collected at the LSC is transferred to the ASC by a combination of

BASEstar request/response transactions and LSC initiated File Transfer Protocol (FTP). After the data has been successfully transferred to the ASC, the ASC will process the data and pass it to the Work Stream (WS) product on the OIS system. After reaching the OIS, the data is made available for analysis and manipulation by other software. For more details of the ASC to LSC communication please refer to [4].

### 2.3.6 FDDI Dual Ring of Trees[11]

A typical FDDI network consists of the following four types of nodes : Dual Attached Stations (DAS), Dual Attached Concentrators (DAC), Single Attached Stations (SAS), and Single Attached Concentrators (SAC).

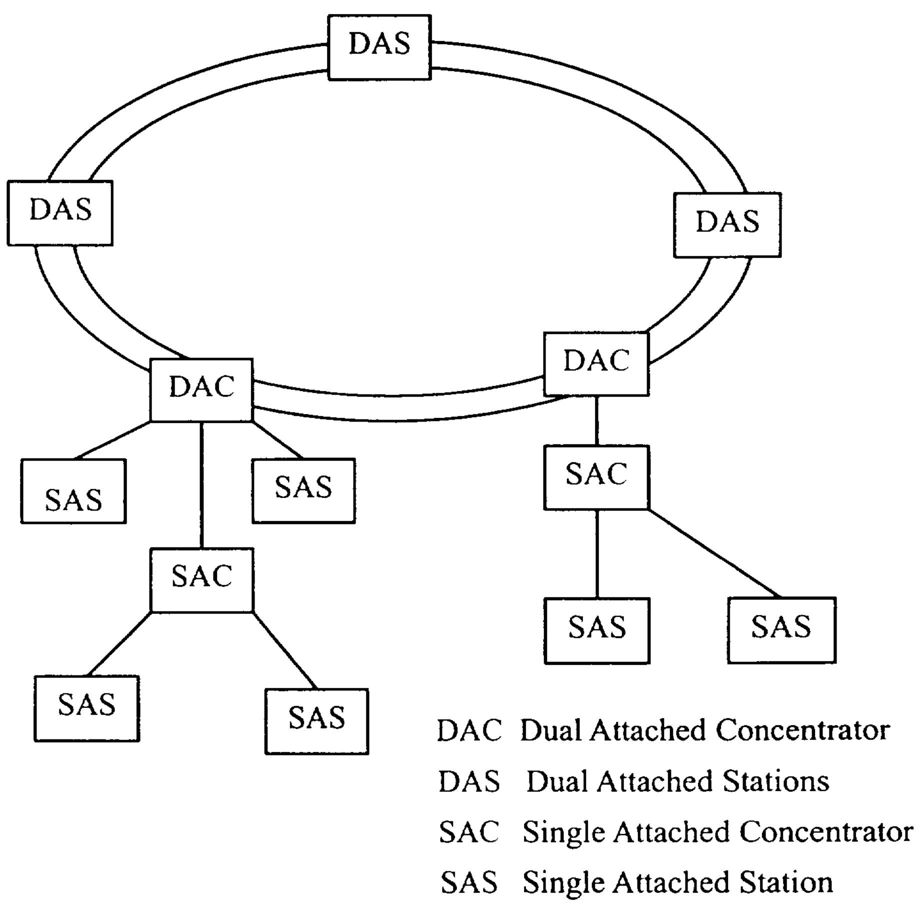


Figure 2.6 FDDI Dual Ring of Trees

A preferred FDDI topology consists of a dual ring of trees. The trunk ring is formed with dual attached stations and concentrators. The trees are formed from concentrator connections to SAS and SAC. Typically the dual ring itself would consists of concentrators, bridges, routers, file servers, main frame computers, etc. Workstations and other desktop computers would be connected through concentrators to form trees.

The use of concentrators to form tree structures offers a number of advantages. It allows lower cost SASs to be connected to the ring. It enhances network reliability since a concentrator automatically reconfigures the network as stations are inserted or deleted from the tree. It also rejects links that are faulty and ensures that they do not bring down the ring. A concentrator also allows the use of a star wiring topology.

### 2.3.7 One Logical FDDI Ring at the ASRM Site

A simplified figure of the network structure at the ASRM is shown in Figure 2.7. Comparing Figures 2.6 and 2.7 shows that logically a dual ring of trees exists at the ASRM site. Although physically it is a point–to–point connection, the overall network structure will have one logical FDDI ring acting as a backbone for the whole complex.

## 2.4 Data Rates for the Workstations and the Workcells

### 2.4.1 Data Rate for the Workstations

The data rate for the workstations can be computed by assuming that the workstation will be sending a block of data such as a text or graphics screen. A page of graphics was assumed to be 640 pixels by 480 lines with 16 colors (4 bits). This is equal to 1.2288 Mbits (640 x 480 x 4) which is equal to 153.6 kilobytes of data to be transmitted. The number of packets required

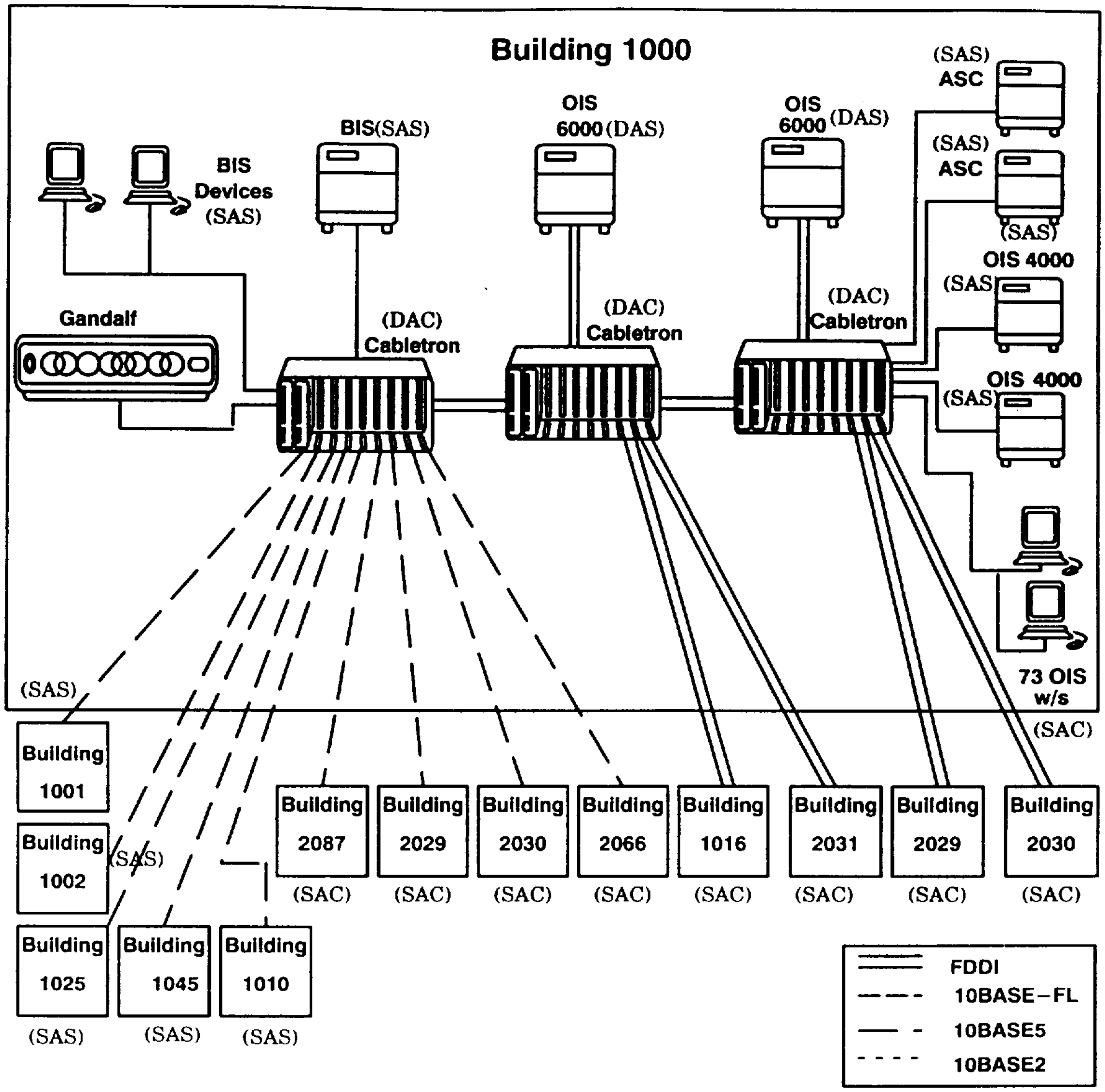


Figure 2.7 FDDI Ring at the ASRM Site

to send 153.6 kilobytes was calculated using 750 byte (6000 bit) packets. The delay per graphics page was calculated by multiplying the number of packets by the delay per packet obtained for 10 sec simulation run.

### 2.4.2 Data Rate for the Workcells

The data rates for the workcells were obtained from RUST [3] and are tabulated in Table 2.5 below.

Table 2.5 Workcells and their data rates

| Bldg No. | Work-cell ID # | Description | Work-cell type | Data Rates | Dura-tion |
|---|---|---|---|---|---|
| B_1016 | W 102 | Robotic washout station | MFG | 441.6 bytes/sec | 24 hrs |
| | W 104a | Hydrotest equipment | Testing | 441.6 bytes/sec | 6 times/ month |
| | W 104b | Hydrotest data acquisition system | Testing | 441.6 bytes/sec | 6 times/ month |
| | W 107 | Electromag–acoustic eddy current test | NDE | 533 bytes/ day | 16hrs / 3 days |
| | W 114 | Robotic dimensional inspection | NDE | 1.44 Mbytes /day | 12 hrs/ 3 days |
| | W 116 | Aqueous degreaser | MFG | 384 bytes/ sec | 8 hrs |
| | W 117 | Robot clean/paint/osee | MFG | 364.8 bytes/sec | 40 hrs/ 5 days |
| | W 118 | Plastic media blast robot | MFG | 105.6 bytes/sec | 16 hrs/ 5 days |
| | W 121 | Clean, dry, liner robot | MFG | 604.8 bytes/sec | 16 hrs/ day |
| | W 148 | Horizontal elastic insulation application | MFG | 268.8 bytes/sec | 60 hrs/ 5 days |
| | W 149 | Pattern cutting station | MFG | 720 bytes/ sec | 4 hrs/ day |
| | W 159 | Aqueous degreaser | MFG | 384 bytes/ sec | 8 hrs |
| | W 160 | Plastic media blast robot | MFG | 652.8 bytes/sec | 8 hrs/ 5 days |
| | W 161 | Component Washout Robot | MFG | 182.4 bytes/sec | 8 hrs/ 5 days |
| | W 168 | Ultrasonic inspection | NDE | 533 bytes/ day | 16 hrs/ 3 days |
| | W 169 | Autoclave (insulation curing) | MFG | 86.4 bytes/sec | 40 hrs/ 5 days |
| B_2029 | DCS | Mix/Cast distributed control system | MFG | 960 bytes/ sec | 96 hrs/ month |
| B_2030 | W 402 | Real time radiography | NDE | 800 bytes/ hr | 40 hrs/ 3 days |

Table 2.5 (continued)

| Bldg No. | Work-cell ID# | Description | Work-cell Type | Data Rates | Dura-tion |
|---|---|---|---|---|---|
| | W 403 | Ultrasonic test | NDE | 800 bytes/ hr | 24 hrs/ 3 days |
| B_2060 | WSSP | Small scale propellant | MFG | 768 bytes/ sec | const-ant |
| | | Scales | MFG | 18816 by-tes / day | const-ant |
| B_2076 | MTRQ | Motor qualification data acquisition system | Test-ing | 576 Kbytes/ sec | 6 times/ month |
| B_3003 | | Propellant removal station | MFG | 441.6 by-tes/sec | 24 hrs |
| B_3005 | | Thermal treatment control | MFG | 384 bytes/ sec | 8 hrs |
| B_3011 | | Feeder preparation | MFG | 384 bytes/ sec | 8 hrs |
| B_3010 | | Incinerator | MFG | 384 bytes/ sec | 8 hrs |

## 2.5 Data Flow over the Network

### 2.5.1 Data Flow for the Manufacturing Intensive Buildings

There is an FDDI data path between the manufacturing intensive buildings and B_1000. Buildings 1016, 2029, 2030, and 2031 are the manufacturing intensive buildings, and each will have a hub directly connected to an OIS hub in B_1000. The workstations in these buildings will be communicating with the OIS 6000 computers. The workcells in these buildings will communicate via the OIS hub with the two ASCs.

2.5.2 Data Flow for the Manufacturing Non–Intensive Buildings

There is a 10BASEFL data path between B_1000 and the manufacturing non–intensive buildings 1001, 1002, 1010, 1025, and 1045. All other manufacturing non–intensive buildings will be connected to B_1000 through the nearest manufacturing non–intensive hub in buildings 2029, 2066, and 2030. The workstations in all the manufacturing non–intensive buildings will communicate via the BIS hub with the two OIS 4000 computers.

CHAPTER 3.0

# BONeS MODELING

## 3.1 Network Simulation

### 3.1.1 Different methods of Network Modeling [16]

Network modeling can be done by several different means, each having its advantages and disadvantages. The first method is by developing a mathematical model of the network, normally using queueing theory. This model can then be used to provide data about the performance of the network. Due to the simplifying assumptions required to use this type of modeling, it is often not the best possible model and frequently is not feasible.

The second approach to analyze the performance of a network is to actually build the network. Although this approach provides very good results, it is normally very expensive, both in time and resources.

The third approach is that of computer simulation. Using a computer simulation the user can model the network to as close to reality as desired. This approach is less expensive than building the network. The major disadvantage of this approach is insuring that the simulation model accurately models the intended network.

### 3.1.2 BONeS Simulator [20]

The Block Oriented Network Simulator (BONeS) provides an interactive graphical environment for simulation–based analysis and design of a broad range of communication networks. The integrated BONeS environment includes the capability to :

1. Graphically describe data structures in a hierarchical fashion.
2. Graphically describe protocol functions, node processing, and network topology in a hierarchical fashion using block diagrams.
3. Translate the network model into a C program, and execute an event driven simulation of the model.
4. Perform design iterations and tradeoff analysis.
5. Document both models and results.

BONeS provides an easy–to–use modeling and simulation environment, an excellent model library that is user extensible, and a set of powerful analysis tools. BONeS minimizes the amount of code the user has to write and provides on–line help, documentation aids, and error checking. These features free the user from the low level details of simulation programming and directs the focus on modeling, analysis, and design.

In the BONeS environment, the network model is specified in terms of the network topology, traffic, packet and message (data) structures, and protocol functions. The user constructs the network graphically and hierarchically using the building blocks from the BONeS model library.

## 3.2 Network Modeling using BONeS

Simulation model design consists of three elements : data structures, modules, and a system. The modules in BONeS control the flow of the data structures. Many basic modules are provided with BONeS, such as decision nodes, random traffic generators, and fixed delays. These can be combined to form new modules to meet the specific needs of the simulation [20].

BONeS is an event driven simulation. All events except traffic generators are triggered by a previous event called a Trigger. If a block is not triggered then there will be no output. Thus when building a model using the provided blocks, race conditions such as parallel inputs must be avoided. Instead, blocks should be cascaded to prevent race conditions.

The different nodes that are constructed in this simulation are workstation and workcells. Models of other nodes, such as CSMA / CD nodes, FDDI nodes, and bridges are included in the BONeS library.

### 3.2.1 CSMA/CD Workstation Model

BONeS comes with a complete model for a CSMA/CD workstation which includes the carrier sense, collision detection, exponential backoff, attempt limit, slot time, and the interframe gap. For a worst case analysis the packet size will be 64 bytes. If the packet size is small the transmission time will be small with respect to the propagation delay, and more collisions will occur [17]. The parameters of the CSMA / CD nodes are set to the IEEE 802.3 CSMA / CD standard and are listed below :

- Backoff limit = 10
- Attempt limit = 16
- Slot time = 5.12 x $10^{-5}$ seconds
- Interframe gap = 96 bits
- Transmission speed = 1 x $10^{-7}$ bits per second

### 3.2.2 FDDI Backbone Model

The parameters of the FDDI backbone model for the ASRM network were set similar to the FDDI backbone model of the campus–wide network example included in the version 2.0 of BONeS[20]. The parameters are listed below :

- Capacity = 100 Mbps
- Target Token Rotation Time = 0.01 seconds
- Operational Target Rotation Time = 0.01 seconds
- Propogation Delay (FDDI) = 1.0 x $10^{-5}$ seconds
- Ring Latency = 6.006 x $10^{-5}$ seconds
- Synchronous Allocation = 0.0 seconds
- Synchronous Buffer Size = 0
- Asynchronous Buffer Size = 2000 elements

### 3.2.3 Cabletron MIM Model

A MIM is an add–on card that can be plugged into a slot of a MMAC. Each MIM has ports on its faceplate to support cabling. Each MIM functions uniquely as a repeater or as a bridge. The model of the repeater MIM passes all frames that are received on the receive port to all transmitting ports with delay. The delay information for each MIM was obtained from [24]. Table 3.1 gives the list of BONeS modules used for each MIMs at the ASRM site.

Table 3.1 BONeS Modules for the MIMs

| Name of the MIMs at the ASRM site | Type of the device | BONeS Module that are used |
|---|---|---|
| Cabletron EMME card | Ethernet bridge | CSMA / CD Bridge |
| Cabletron FDMMIM | FDDI to Ethernet bridge | FDDI to CSMA / CD Bridge |
| Cabletron MT8–MIM | DELNI card | Fixed Delay |
| Cabletron FORMIM | 10BASE–FL card | CSMA / CD hub |
| Cabletron TPRMIM | 10BASE–T card | CSMA / CD hub |
| Cabletron CXRMIM | DEMPR card | CSMA / CD hub |
| Cabletron GX–M | GatorStar card | LocalTalk to CSMA / CD router. |
| Cabletron FDMIM–04 | FDDI concentrator | FDDI hub |

### 3.2.4 Traffic Source Model

A traffic source model was developed to model a workstation sending a block of data such as a text or graphics screen. The traffic source model sends a set number of packets at an interarrival rate set by the user. The interarrival rate was modeled with a Poisson distribution because traffic on a LAN tends to have a Poisson distribution [18].

## 3.3 BONeS Modules for ASRM Sub-networks

The different BONeS modules developed for this simulation are as shown in Table 3.2

Table 3.2 BONeS Modules for ASRM Sub–networks

| BONeS Module (indicated in upper left on each figure) | MMAC to which the module is connected | Devices in this module | Destination |
|---|---|---|---|
| ASRM Network | | | |
| MAC–Network | MMAC in Switch Rm 210 in B_1000 | 80 MAC w/s | 3 modules to BIS 6310 and 2 modules to BIS 6420_A |
| B_2087_NI | Non–Intensive MMAC in B_1012 | 14 MAC w/s in B_1012 | BIS 6420_A |
| RM 507 | MMAC in Comp Rm 507 in B_1000 | 50 PCs, 7 SGIs with a server | BIS 6420_B |
| Printer–CAD–ENG | MMAC in Switch Rm 210 in B_1000 | 25 CAD w/s with 5 servers, 31 ENG with 9 servers and 32 MAC printers | BIS 6420_B |
| RM 638A | MMAC in Switch Rm 638 in B_1000 | 80 MAC w/s | BIS 6420_B |
| B_2029_NI | Non–Intensive MMAC in B_2029 | 8 w/s in B_2028<br>1 w/s in B_2082 | OIS 4000_A |
| B_2030_NI | Non–Intensive MMAC in B_2030 | 4 w/s in B_2042<br>3 w/s in B_3005<br>1 w/s in B_3011<br>1 w/s in B_4001 | OIS 4000_A |
| B_2066_NI | Non–Intensive MMAC in B_2066 | 3 w/s in B_1032<br>1 w/s in B_2070 | OIS 4000_A |
| RM 638B | MMAC in Switch Rm 638 in B_1000 | Gandalf Terminal server | OIS 4000_A |
| OIS–Workstations | MMAC in BIS Hub in B_1000 | 73 OIS MAC w/s | OIS 4000_B |
| B_1001_NI | MMAC in BIS Hub in B_1000 | 3 w/s in B_1001 | OIS 4000_A |
| B_1045_NI | MMAC in BIS Hub in B_1000 | 4 w/s in B_1045 | OIS 4000_A |

Table 3.2 (continued)

| BONeS Module (indicated in upper left on each figure) | MMAC to which the module is connected | Devices in this module | Destination |
|---|---|---|---|
| B_1010_NI | MMAC in BIS Hub in B_1000 | 10 w/s in B_1010 | OIS 4000_A |
| B_1002_NI | MMAC in BIS Hub in B_1000 | 1 w/s in B_1002 | OIS 4000_A |
| B_1025_NI | MMAC in BIS Hub in B_1000 | 1 w/s in B_1025 | OIS 4000_A |
| B_1016_I | Intensive MMAC in B_1016 | 27 w/s in B_1016<br>16 w/c in B_1016 | OIS 6000_A<br>ASC_A |
| B_2029_I | Intensive MMAC in B_2029 | 12 w/s in B_2029<br>1 w/c in B_2029<br>4 w/s in B_2060<br>2 w/c in B_2060<br>4 w/s in B_2076<br>1 w/c in B_2076 | OIS 6000_B<br>ASC_B |
| B_2030_I | Intensive MMAC in B_2030 | 3 w/s in B_2030<br>2 w/c in B_2030<br>1 w/c in B_3003<br>1 w/c in B_3005<br>1 w/c in B_3010<br>1 w/c in B_3011 | OIS 6000_B<br>ASC_B |
| B_2031_I | Intensive MMAC in B_2031 | 15 w/s in B_2031 | OIS 6000_A |

All the modules created for the ASRM network are shown in Appendix A1.

## 3.4 Probes and the Iterations Setting

Several probes were placed throughout the network to gather statistics during the simulation. The mean delay per packet, received throughput, transmitted throughput, and the number of completed packets were collected for each separate link. Each iteration interval was divided into ten batches in order to collect these statistics.

### 3.4.1 Delay and Throughput Measuring Probes

These statistics were collected by placing a Generic Probe on the Media Access Control (MAC) Statistics module in each link. The MAC Statistics module was used to measure the delay and throughput for all CSMA/CD workstation models on one link. All CSMA/CD workstation model MAC instances share the same memory. Therefore, all the CSMA/CD workstation models write the delay and throughput into one memory. These statistics are then made available to the Post Processor in BONeS by placing a Generic Probe on the MAC Statistics Compute module.

### 3.4.2 Iteration Settings

The traffic intensity per node was varied from 10 Kbps to 90 Kbps at twelve points during the simulation. The traffic intensity was varied with an exponential function to show the knees of the curves. Different simulation runs were made by setting the simulation time per iteration to one, two, and ten seconds. The actual computer time to simulate and record one second of actual network operation was approximately 30 hours on a moderately–loaded Sun 600/MP with 128 Megabytes of memory.

## CHAPTER 4.0

## ANALYSIS AND RESULTS

### 4.1 Network Expectations

The network should be reliable and have redundant links since the control of the manufacturing will be accomplished over the LAN. Large amounts of data will be required due to the extensive monitoring and documentation required for the manufacture of the solid rocket motors in the Space Shuttle program [2].

### 4.2 Network Evaluation Parameters

The two primary evaluation parameters used to judge the network performance are throughput and delay. The throughput is the effective bit rate of the system in bits per second (bps). It does not include the overhead bits used by the protocol or the packets that have to be re–transmitted. The delay in a LAN is determined by the mean delay per packet [15].

The delay in a LAN is mostly caused by the following three factors: the propagation delay, the delay in a transceiver, and the queuing delay in a bridge. Also the user response time is important. These delays are modeled using several different techniques in the simulation.

### 4.2.1 Propagation Delay

The propagation delay of the light signal traveling down the fiber is modeled by using a fixed delay model provided by BONeS. The link delay is calculated by dividing the distance by the speed at which the light travels down the fiber (0.67 times the speed of light) [2].

### 4.2.2 Delay in a Transcevier

The worst case collision detection time of a particular CSMA/CD commercial transceiver was found to be 900 nanoseconds [21]. The worst case packet delay of a particular commercial optical hub was found to be 630 nanoseconds [21]. This delay is caused by the optical–to–electrical and electrical–to–optical conversion. These delays are also modeled by a fixed delay in the simulation [2].

### 4.2.3 Queue Delay in a Bridge

In the simulation model each of the CSMA/CD networks is connected to the FDDI backbone by a bridge. A bridge converts the CSMA/CD packet to an FDDI packet and buffers the incoming packets until they are serviced. If a packet enters the bridge and the queue is full, the packet is discarded. If the queue is large but not full, then the packet will be delayed.

## 4.3 Mean Delay and Throughput Plots

The statistics collected with the probes during the simulation are plotted to judge the performance of the network. Different simulation runs were made by setting the simulation time per iteration to one, two, and ten seconds. The mean delay per packet and throughput are plotted versus the offered traffic intensity. These plots are created using the Post Processor in

BONeS and show the performance of the network at each iteration of the traffic intensity during the simulation.

### 4.3.1 BIS Devices Mean Delay Plots

The mean delay per packet versus the offered traffic intensity plots are shown in figures 4.1, 4.2, and 4.3. The BIS devices delay plot shows a rising curve.

In the case of the BIS devices plot, the mean delay per packet increases as the offered traffic intensity increases. The delay curves level out close to a traffic intensity of 40 Kbps per node and then start to climb linearly. This agrees with the generally accepted assumption that a CSMA/CD network overloads at somewhere between 30% and 50% of its maximum transmission speed [15]. Note that the transmission speed of a link (10 Mbps for Ethernet) equals the traffic intensity per node times the number of nodes. There are approximately 80 nodes per link in the BIS section; 80 nodes transmitting at 40 Kbps is 3.2 Mbps. The simulation only calculates delays per packet for successful packet transmissions and does not include lost packets.

### 4.3.2 BIS Devices Throughput Plots

The throughput versus the offered traffic intensity plots are shown in figures 4.4, 4.5, and 4.6. The BIS devices throughput plot shows a rising curve.

The curves in these figures show that the throughput increases linearly with the offered traffic intensity per node. When multiple subnets saturate, the actual amount of traffic injected into the network is limited. So, the throughput of larger networks increases at a slower rate at higher traffic intensity per node. The analysis of the mean delay per packet shows that the delay curve levels out close to a traffic intensity of 40 Kbps per node. So the throughput for each of the links should be determined at the traffic intensity of 40 Kbps per node.

Table 4.1. Delay per packet and throughput for the BIS devices

| Link | No of nodes | Mean delay/packet at traffic intensity of 40 kbps in msec | | | Throughput at traffic intensity of 40 kbps in Mbps. | | |
|---|---|---|---|---|---|---|---|
| | | 1 sec | 2 sec | 10 sec | 1 sec | 2 sec | 10 sec |
| MAC Network | 80 | 3.0 | 2.5 | 3.0 | 3.4 | 3.3 | 3.2 |
| Printer Network | 56 | 1.0 | 1.0 | 1.0 | 2.4 | 2.4 | 2.4 |
| B_2087_NI | 14 | 2.0 | 2.0 | 2.2 | 0.6 | 0.6 | 0.6 |
| RM 507 | 57 | 2.0 | 2.0 | 2.2 | 2.5 | 2.4 | 2.4 |
| RM 638A | 80 | 3.0 | 2.8 | 2.6 | 3.4 | 3.2 | 3.2 |

### 4.3.3 Non–Intensive Network Delay Plots

The mean delay per packet versus the offered traffic intensity plots are shown in figures 4.7, 4.8, and 4.9. The Non–Intensive network delay plot shows a knee curve.

In the case of the Non–Intensive network, all the links show a knee at a particular traffic intensity. The mean delay per packet decreases beyond this traffic intensity, because the number of completed packets decreases beyond the knee of each link. Since there is more traffic to be transmitted than the network can handle, packets waiting to be transmitted are queued within the bridge. As the incoming traffic rate is higher than the packet service rate, the queue size grows. At high loads the queue size will grow steadily until the buffer is filled to capacity. Any subsequent incoming packets to the queue will be dropped. The packets that do get through have a smaller delay because the mean delays are only calculated for successful transmissions of the packets in the simulation. This shows that the links are overloaded and only a few nodes can communicate. All other nodes are locked out by the excessive traffic.

The zero values for delay per packet for certain sub–networks indicates that no node in that particular sub–network was able to do any successful transmission of the packets in the specified simulation time run.

The random nature of the delay plot obtained for a 10 sec simulation can be attributed to the heterogeneity of the network and the traffic flow.

### 4.3.4 Non–Intensive Network Throughput Plots

The throughput versus the offered traffic intensity plots are shown in figures 4.10, 4.11, and 4.12. The Non–Intensive network throughput plot shows a rising curve.

The curves in these figures show that the throughput increases linearly with the offered traffic intensity per node. However the analysis of the mean delay per packet shows that the links are overloaded beyond a certain traffic intensity. This is because only a few nodes are able to transmit and all others cannot. The throughput beyond this knee is only available to a few nodes. So the throughput for each of the links should be determined at the traffic intensity where the maximum delay per packet occurred.

Table 4.2. Delay per packet and throughput for the Non–Intensive network

| Link | No of nodes | Maximum delay/ packet (msec) | | | Traffic intensity at maximum delay/ packet (kbps) | | | Throughput at maximum delay per packet (Mbps) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 sec | 2 sec | 10 sec | 1 sec | 2 sec | 10 sec | 1 sec | 2 sec | 10 sec |
| B_1001_NI | 3 | 0.0 | 0.0 | 32.0 | 40 | 40 | 55 | 0.12 | 0.12 | 0.12 |
| B_1045_NI | 4 | 0.0 | 0.0 | 40.0 | 40 | 40 | 55 | 0.16 | 0.16 | 0.16 |
| B_1010_NI | 10 | 23.0 | 23.0 | 86.0 | 40 | 40 | 15 | 0.52 | 0.42 | 0.18 |
| B_2066_NI | 4 | 0.0 | 0.0 | 83.0 | 40 | 40 | 15 | 0.34 | 0.34 | 0.14 |
| RM 638B | 1 | 0.0 | 0.0 | 10.0 | 40 | 40 | 75 | 0.82 | 0.72 | 0.72 |
| B_1002_NI | 1 | 0.0 | 0.0 | 14.0 | 40 | 40 | 75 | 0.04 | 0.04 | 0.04 |
| B_2029_NI | 9 | 23.0 | 23.0 | 83.0 | 40 | 40 | 15 | 0.44 | 0.42 | 0.18 |
| B_2030_NI | 9 | 23.0 | 23.0 | 83.0 | 40 | 40 | 15 | 0.48 | 0.42 | 0.18 |
| B_1025_NI | 1 | 0.0 | 0.0 | 83.0 | 40 | 40 | 15 | 0.04 | 0.04 | 0.02 |

### 4.3.5 Intensive Network Delay Plots

The mean delay per packet versus the offered traffic intensity plots are shown in figures 4.13, 4.14, and 4.15. The Intensive network delay plot shows a knee curve.

In the case of the Intensive network, all the links show a knee at a particular traffic intensity. The mean delay per packet decreases beyond this traffic intensity, because the number of completed packets decreases beyond the knee of each link. Even though the traffic intensity is being increased, many nodes are not given access to the channel. The packets that do get through have a smaller delay because the mean delays are only calculated for successful transmissions of the packets in the simulation. This shows that the links are overloaded and only a few nodes can communicate. All other nodes are locked out by the excessive traffic.

### 4.3.6 Intensive Network Throughput Plots

The throughput versus the offered traffic intensity plots are shown in figures 4.16, 4.17, and 4.18. The Intensive network throughput plot shows a rising curve.

The curves in these figures show that the throughput increases linearly with the offered traffic intensity per node. But the analysis of the mean delay per packet shows that the links are overload beyond a certain traffic intensity. This is because only a few nodes are able to transmit and all others cannot. The throughput beyond this knee is only available to a few nodes. So the throughput for each of the links should be determined at the traffic intensity where the maximum delay per packet occurred.

The throughput plot for building 2029 intensive (B_2029_I) shows a very high value as compared to the throughput plots of other intensive buildings. This is because of the workcell MRTQ connected to it has a data rate of 4.608 Mbps [3].

Table 4.3. Delay per packet and throughput for the Intensive network

| Link | No of nodes | Maximum delay/ packet (msec) | | | Traffic intensity at maximum delay/ packet (kbps) | | | Throughput at maximum delay per packet (Mbps) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 sec | 2 sec | 10 sec | 1 sec | 2 sec | 10 sec | 1 sec | 2 sec | 10 sec |
| B_2031_I | 15 | 3.0 | 3.4 | 9.0 | 65 | 25 | 20 | 1.0 | 0.4 | 0.3 |
| B_2029_I | 24 | 1.5 | 1.5 | 13.0 | 40 | 40 | 20 | 5.1 | 5.0 | 4.6 |
| B_1016_I | 43 | 4.0 | 5.2 | 17.0 | 65 | 25 | 20 | 2.4 | 0.7 | 0.7 |
| B_2030_I | 9 | 1.0 | 1.5 | 16.0 | 40 | 40 | 20 | 0.3 | 0.3 | 0.1 |

## 4.4 Delay per Graphics Page

A page of graphics was assumed to be 640 pixels by 480 lines with 16 colors (4 bits). This is equal to 1.2288 Mbits (640 x 480 x 4) which is equal to 153.6 kilobytes of data to be transmitted. The number of packets required to send 153.6 kilobytes using 750 byte (6000 bit) packets will be 205 packets. The delay per graphics page was calculated by multiplying the number of packets by the delay per packet obtained for 10 sec simulation run. The results are summarized in Table 4.4, 4.5, and 4.6.

Table 4.4 Delay per Graphics page for the BIS devices

| Link | Mean delay/packet (msec) for 10 sec simulation | Delay per Graphics page (msec) |
|---|---|---|
| MAC Network | 3.0 | 615 |
| Printer Network | 1.0 | 205 |
| B_2087_NI | 2.2 | 451 |
| RM 507 | 2.2 | 451 |
| RM 638A | 2.6 | 533 |

Table 4.5 Delay per Graphics page for the Non–Intensive network

| Link | Maximum delay/packet (msec) for 10 sec simulation | Delay per Graphics page (msec) |
|---|---|---|
| B_1001_NI | 32 | 6560 |
| B_1045_NI | 40 | 8200 |
| B_1010_NI | 86 | 17630 |
| B_2066_NI | 83 | 17015 |
| RM 638B | 10 | 2050 |
| B_1002_NI | 14 | 2870 |
| B_2029_NI | 83 | 17015 |
| B_2030_NI | 83 | 17015 |
| B_1025_NI | 83 | 17015 |

Table 4.6 Delay per Graphics page for the Intensive network

| Link | Maximum delay/packet (msec) for 10 sec simulation | Delay per Graphics page (msec) |
|---|---|---|
| B_2031_I | 9 | 1845 |
| B_2029_I | 13 | 2665 |
| B_1016_I | 17 | 3485 |
| B_2030_I | 16 | 3280 |

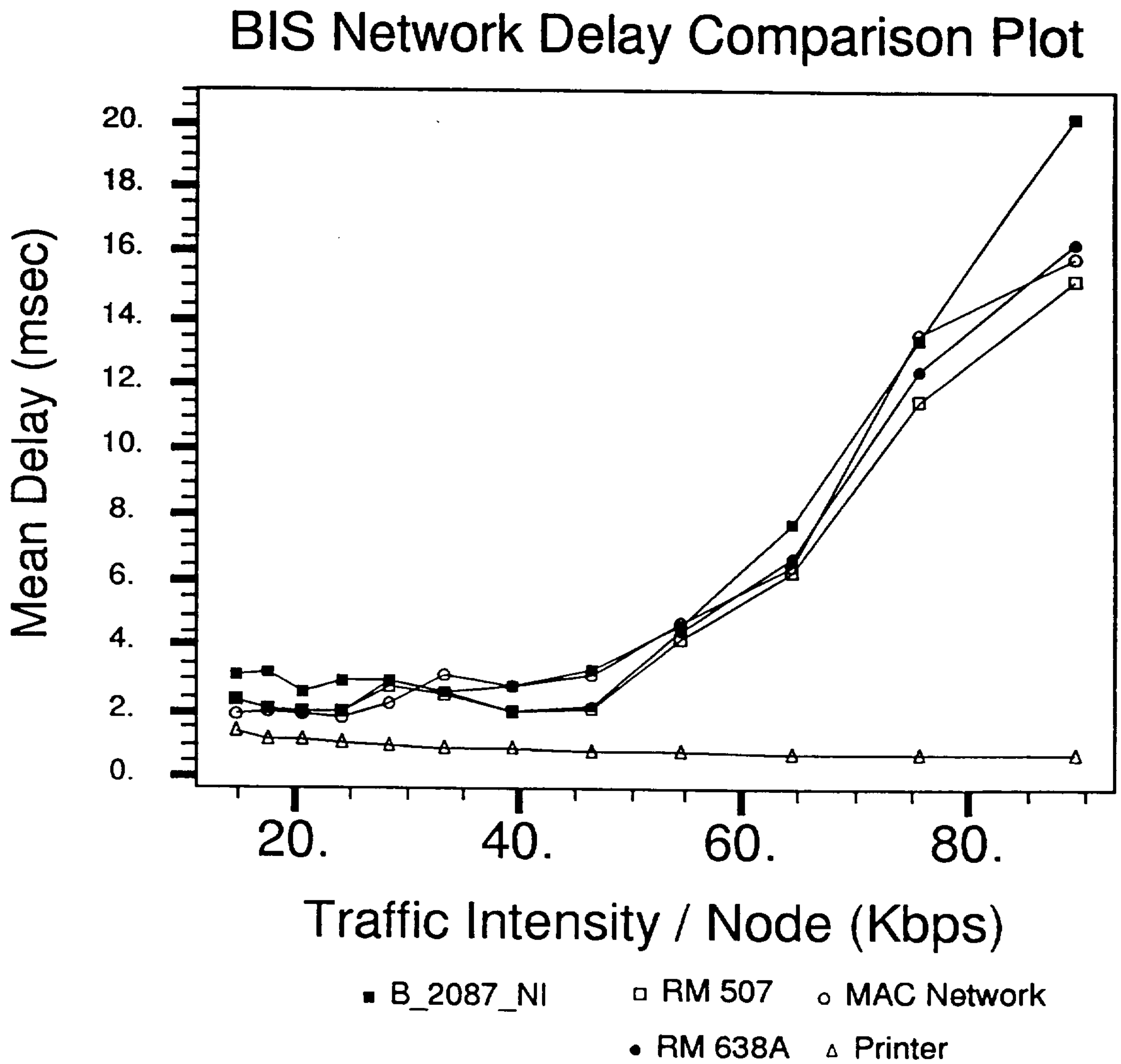


Figure 4.1 BIS devices delay plot for simulation time of 1 second

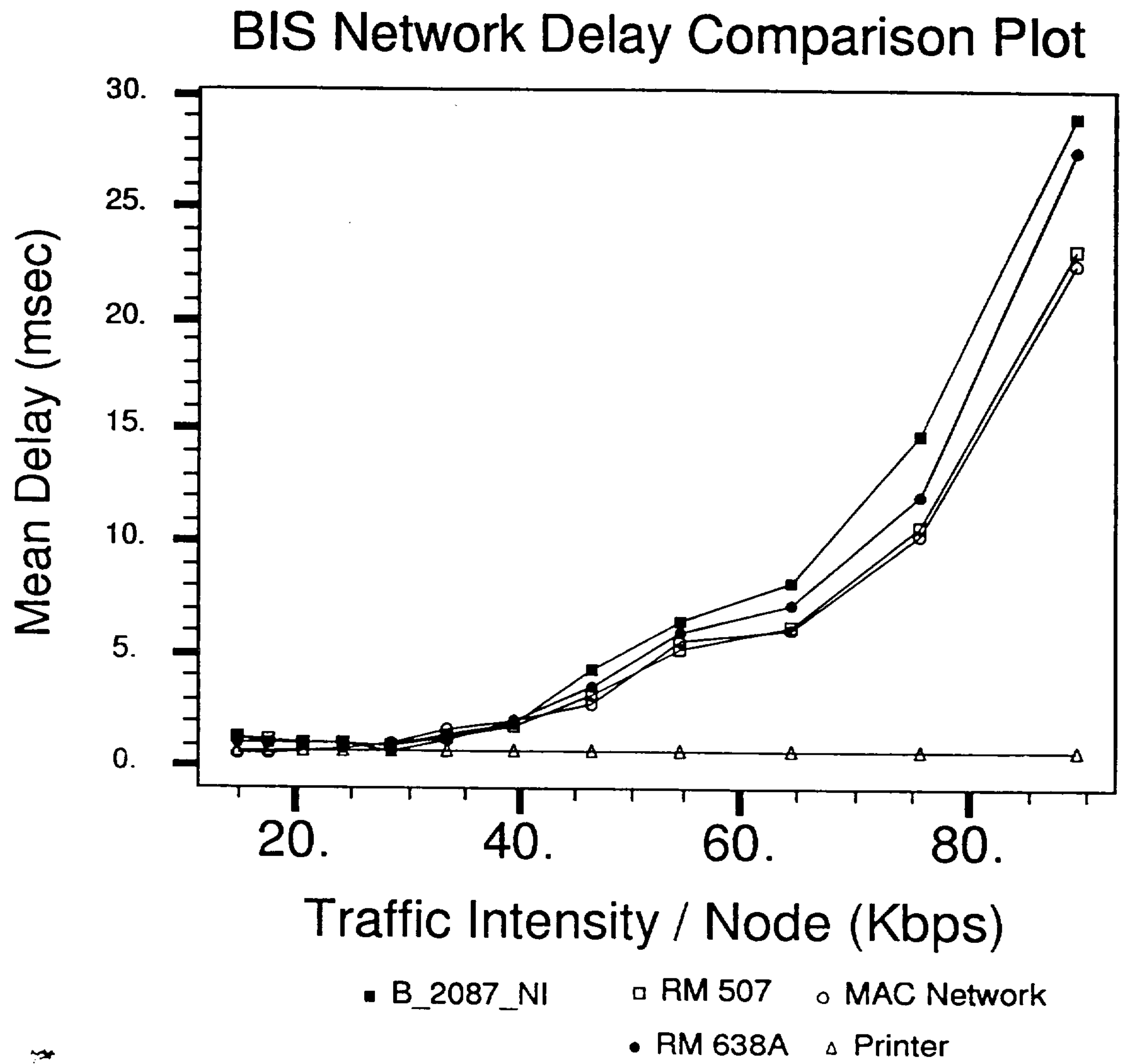


Figure 4.2 BIS devices delay plot for simulation time of 2 second

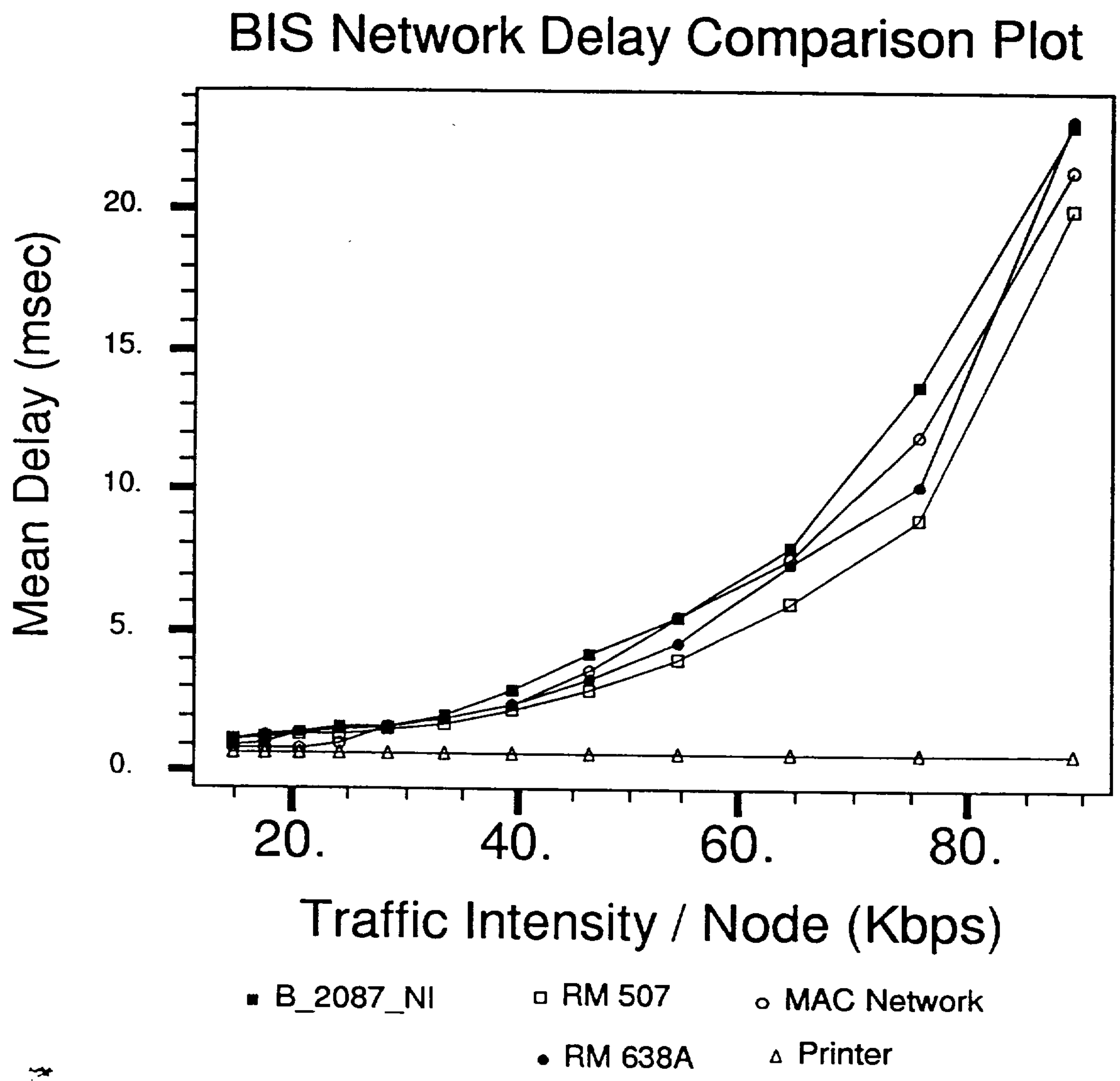


Figure 4.3 BIS devices delay plot for simulation time of 10 second

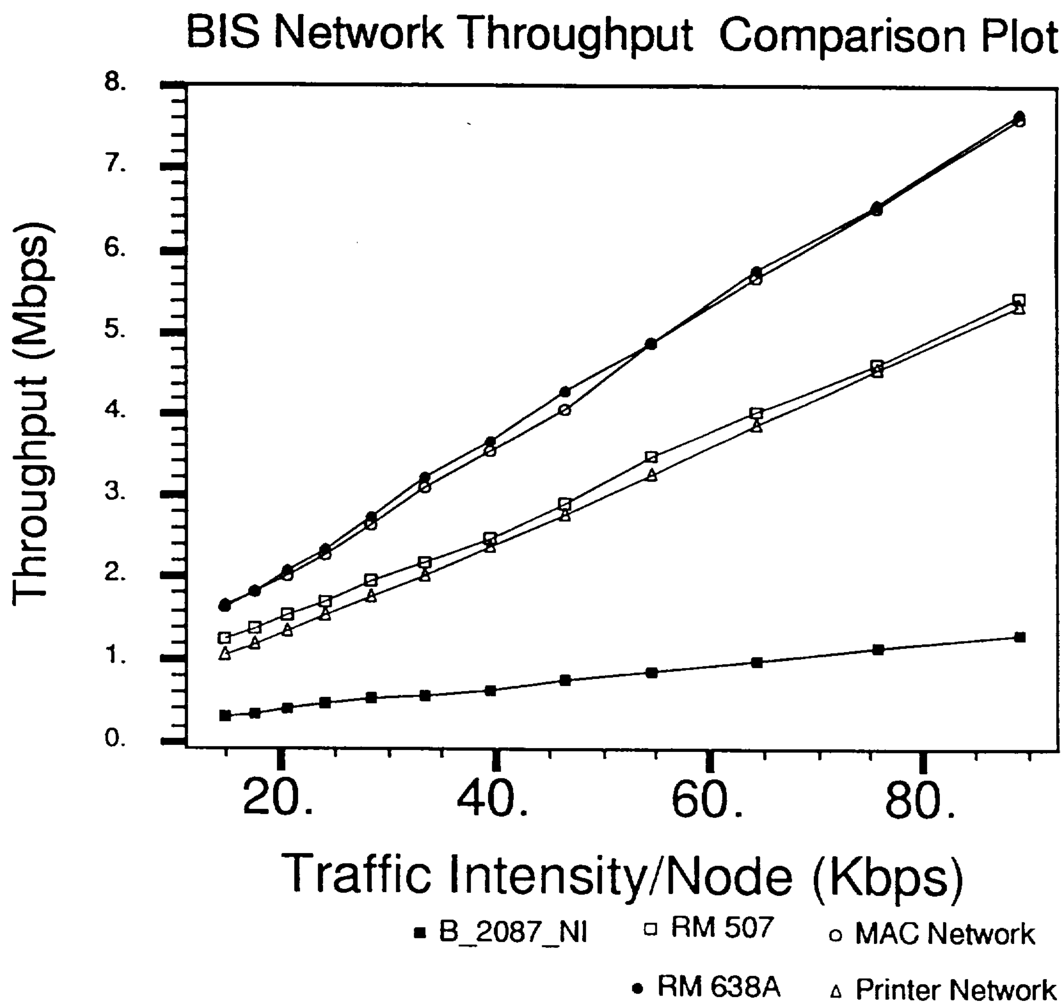


Figure 4.4 BIS devices throughput plot for simulation time of 1 second

C-2.

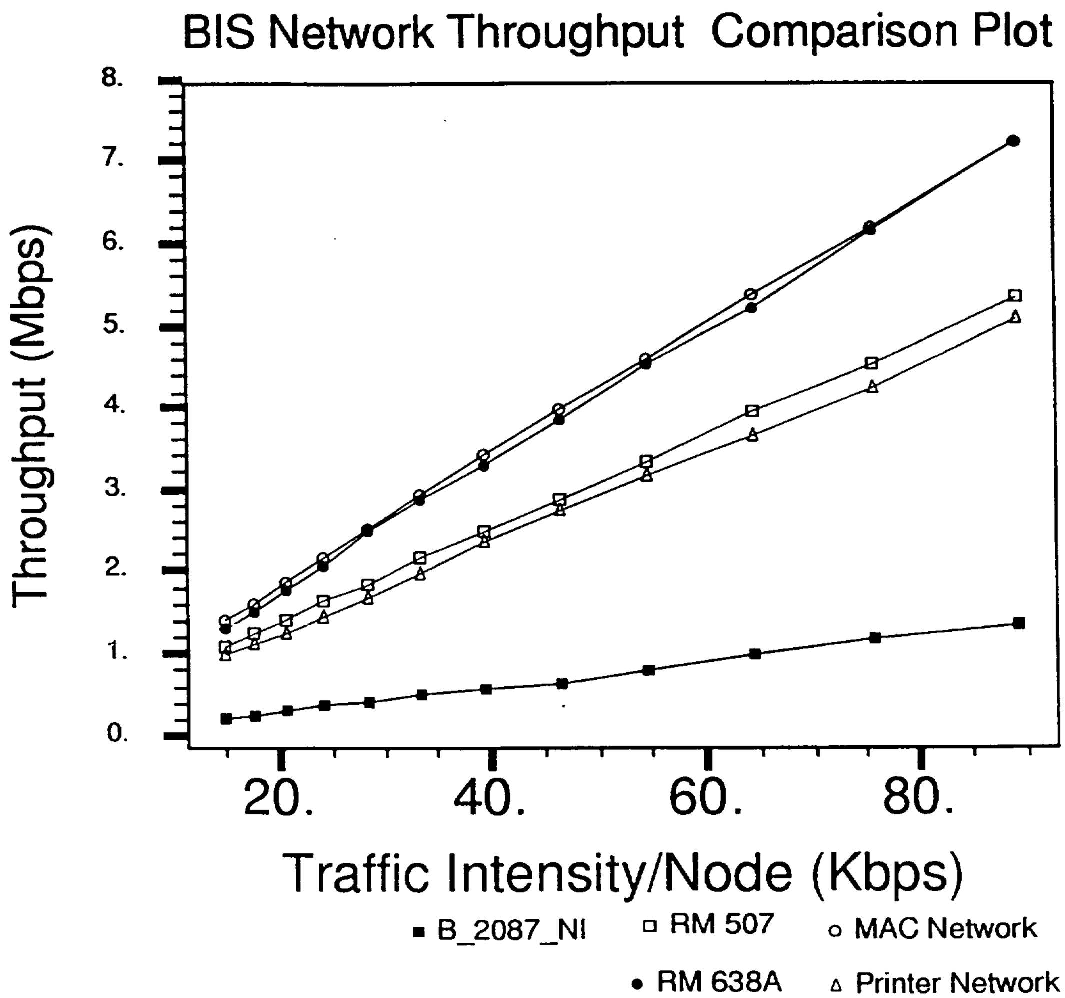


Figure 4.5 BIS devices throughput plot for simulation time of 2 second

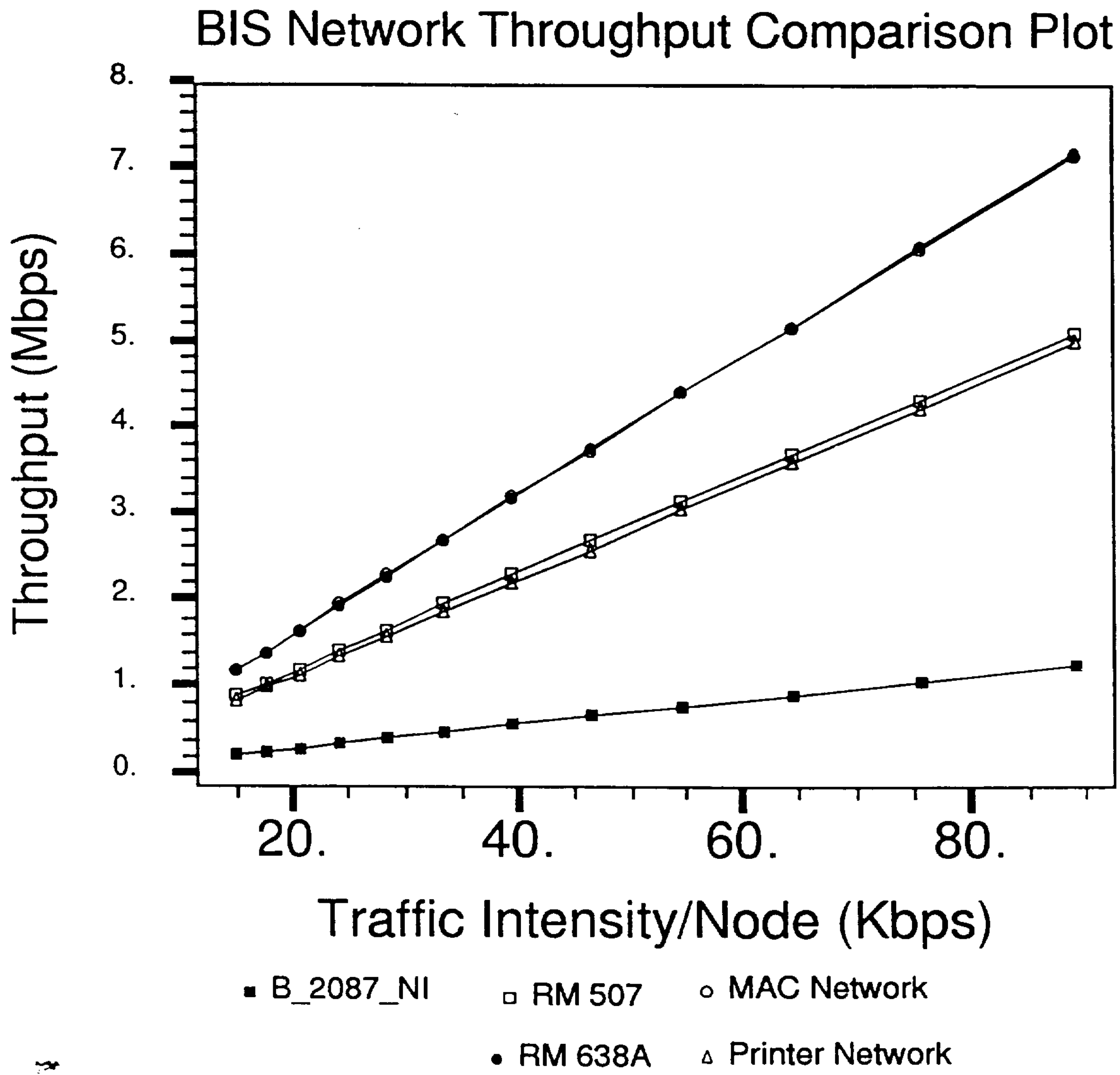


Figure 4.6 BIS devices throughput plot for simulation time of 10 second

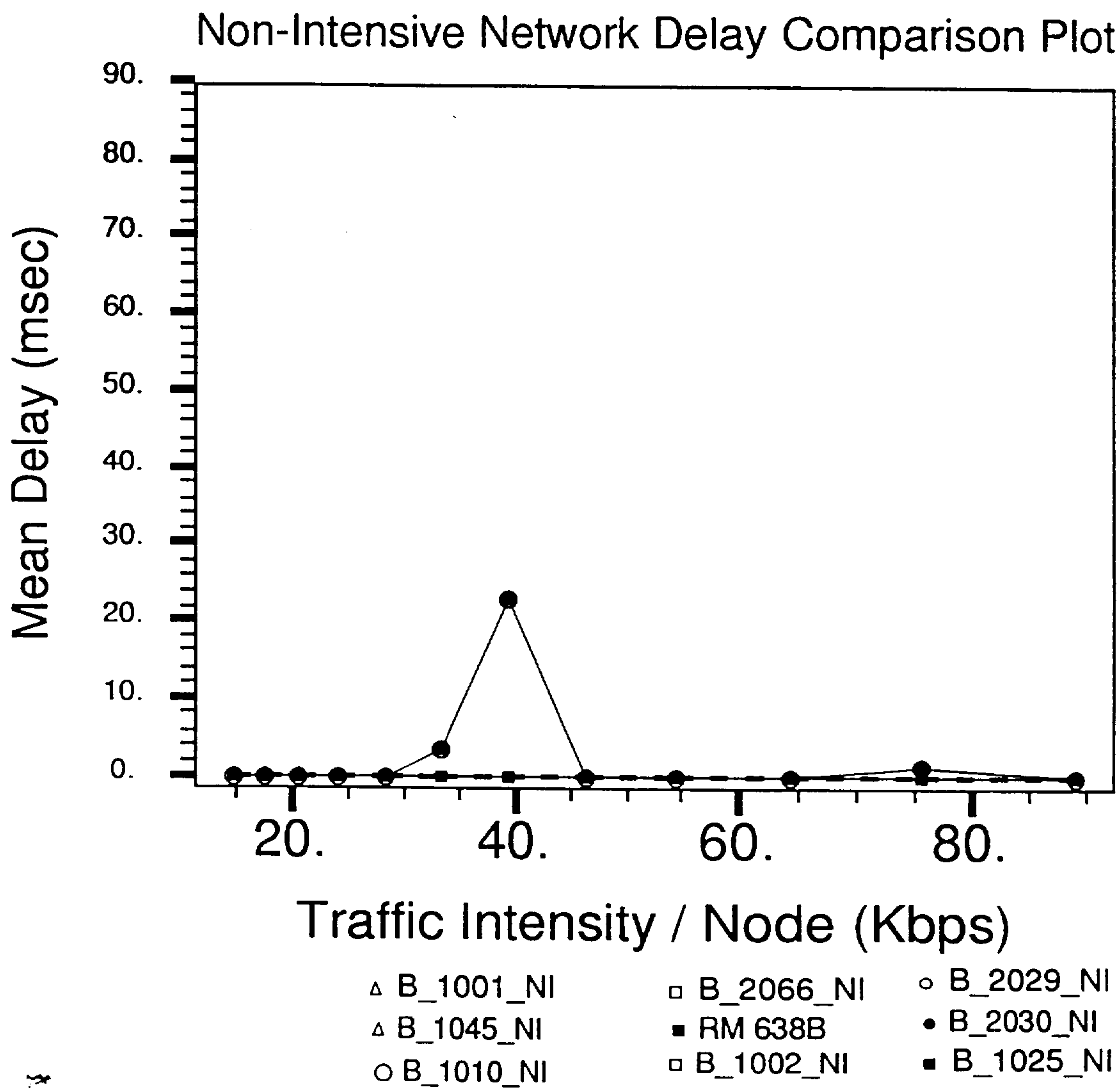


Figure 4.7 Non–Intensive network delay plot for simulation time of 1 second

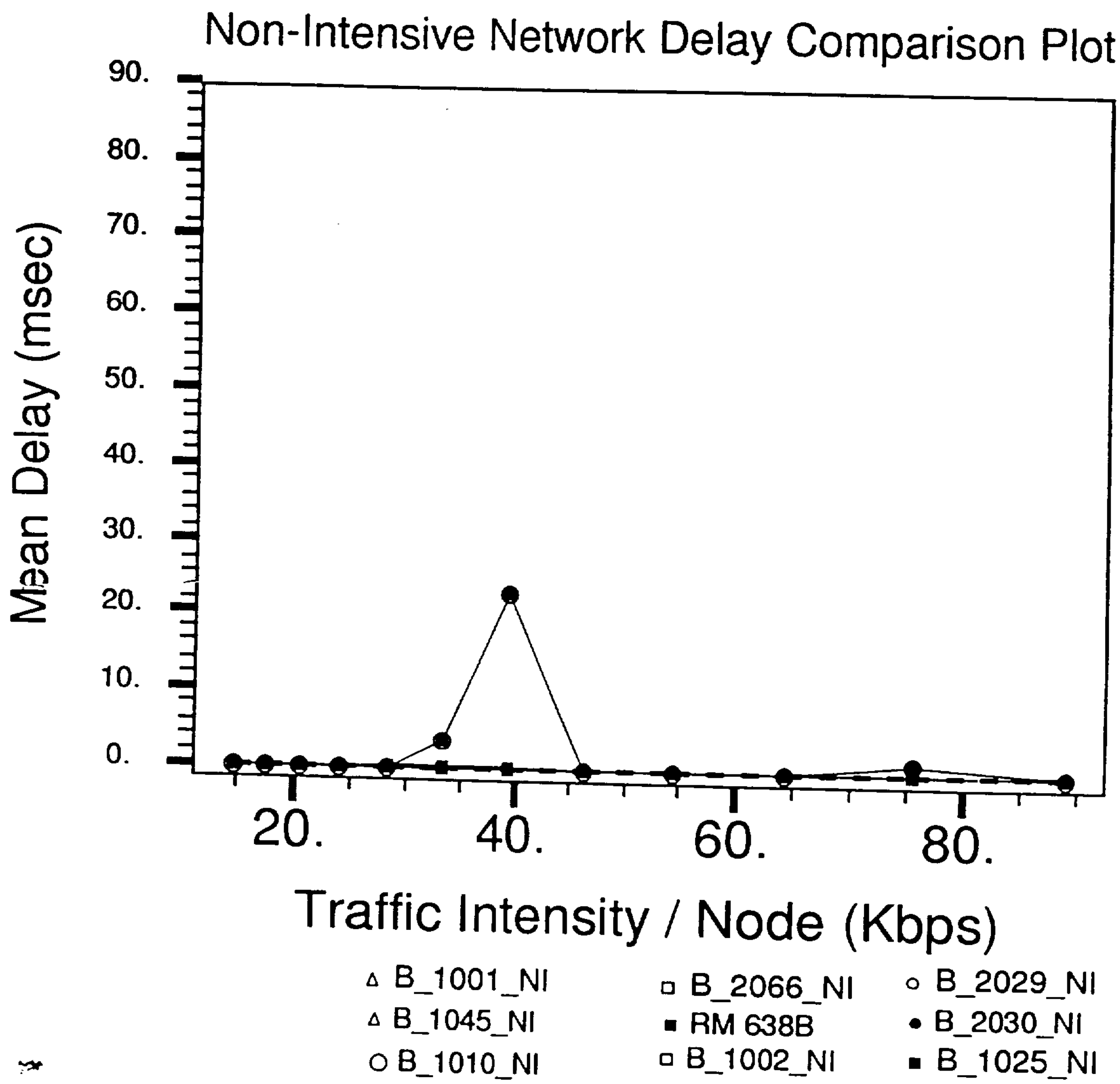


Figure 4.8 Non–Intensive network delay plot for simulation time of 2 second

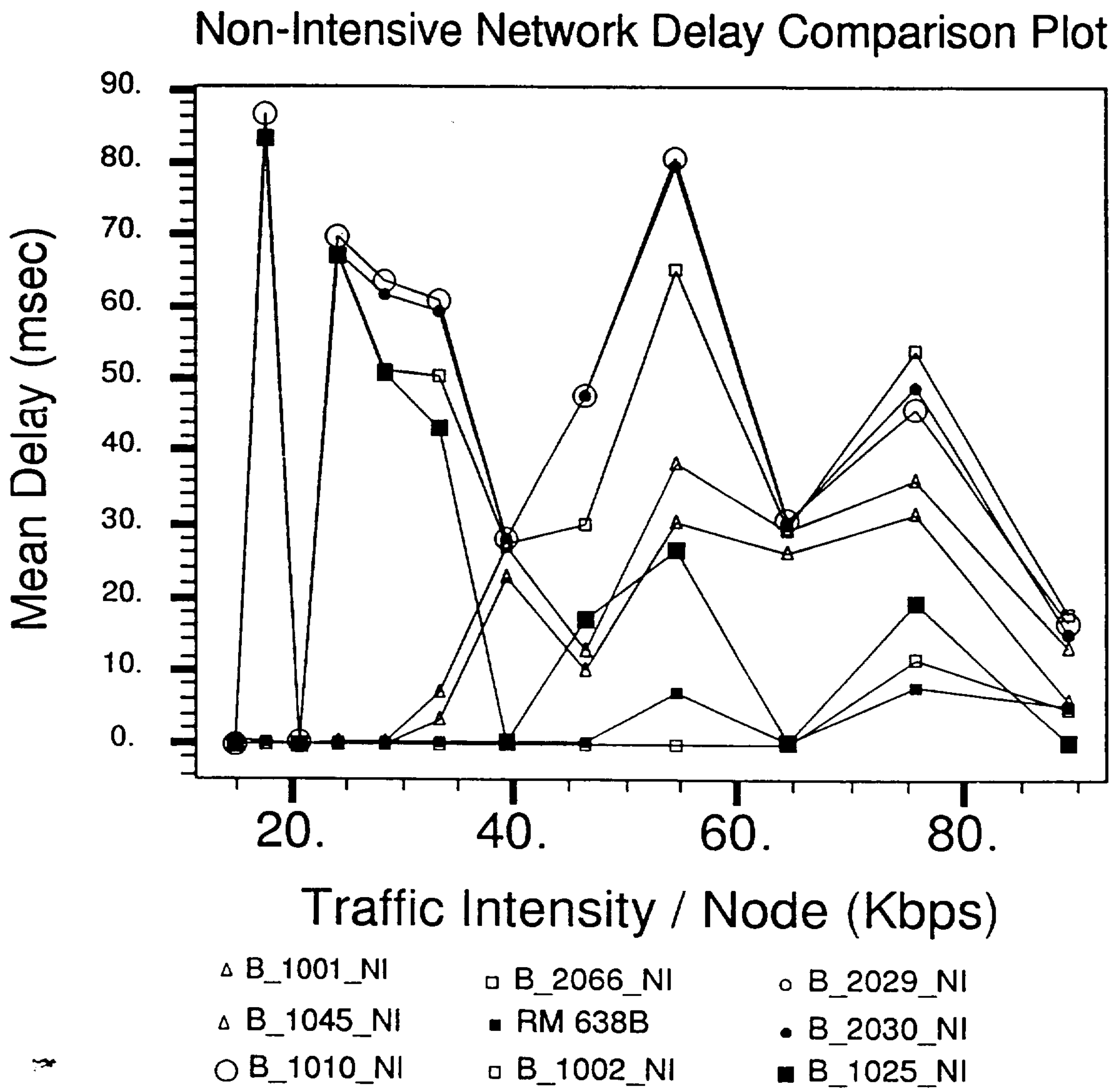


Figure 4.9 Non–Intensive network delay plot for simulation time of 10 second

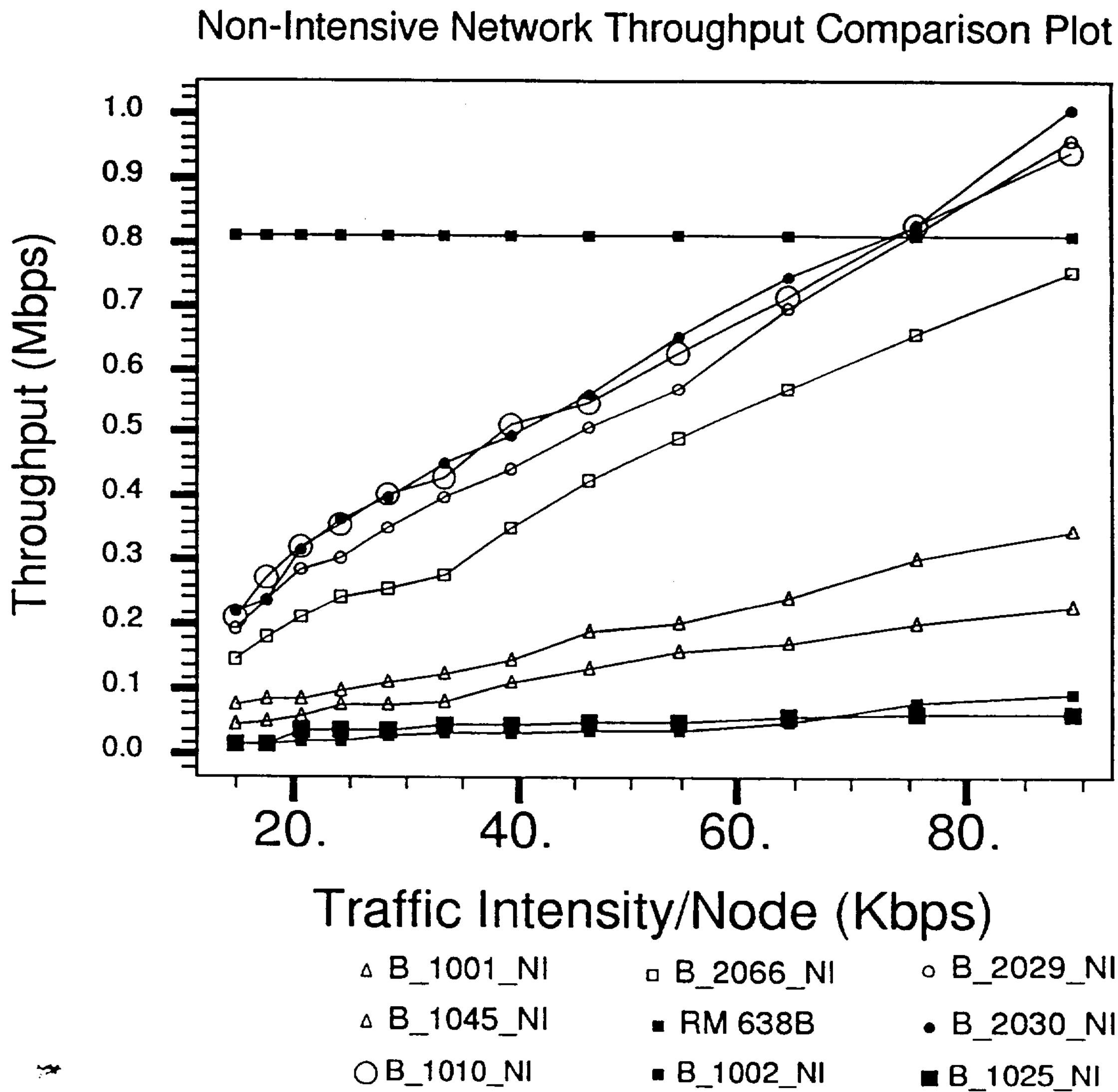


Figure 4.10 Non–Intensive network throughput plot for simulation time of 1 second

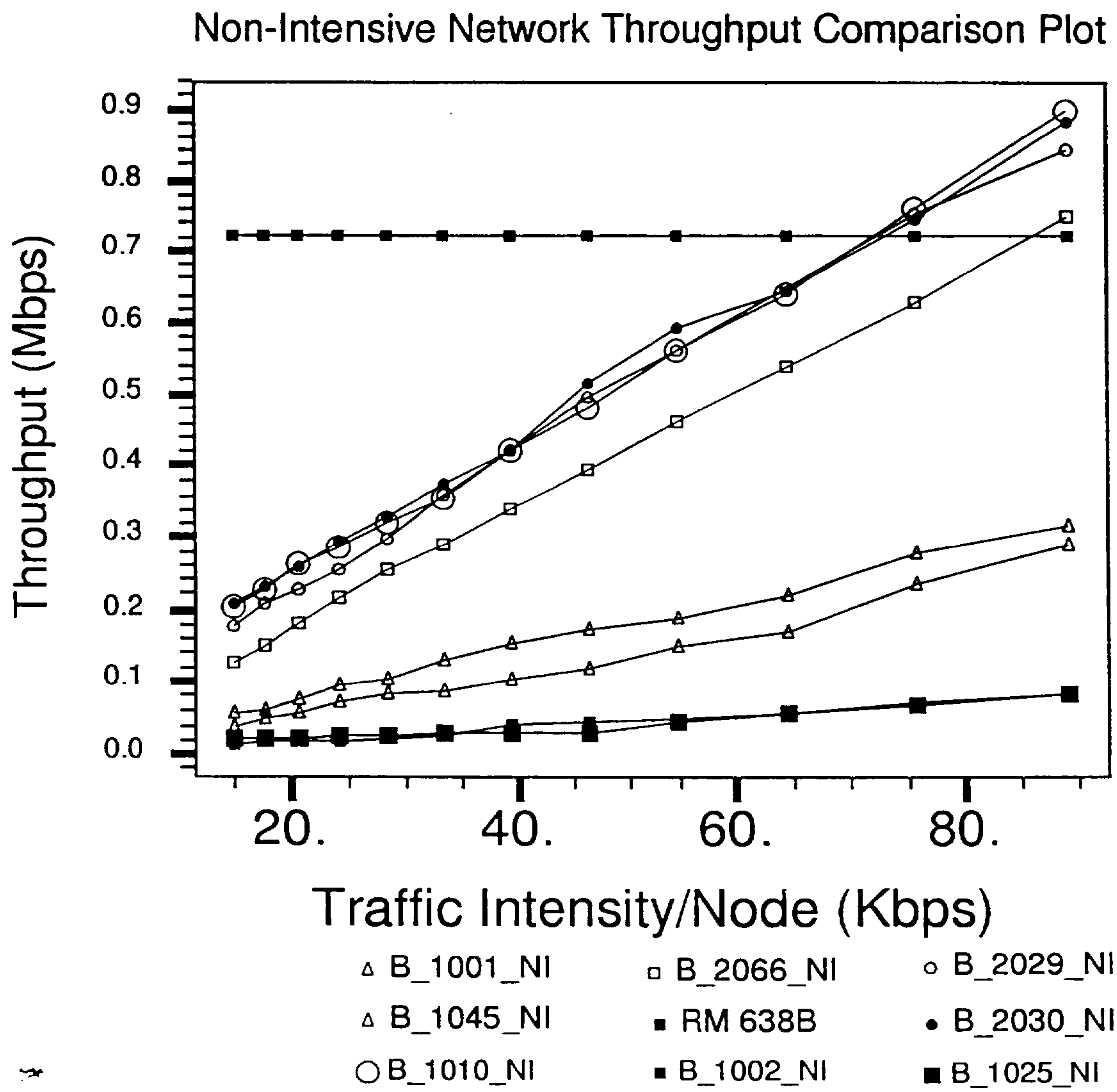


Figure 4.11 Non–Intensive network throughput plot for simulation time of

2 second

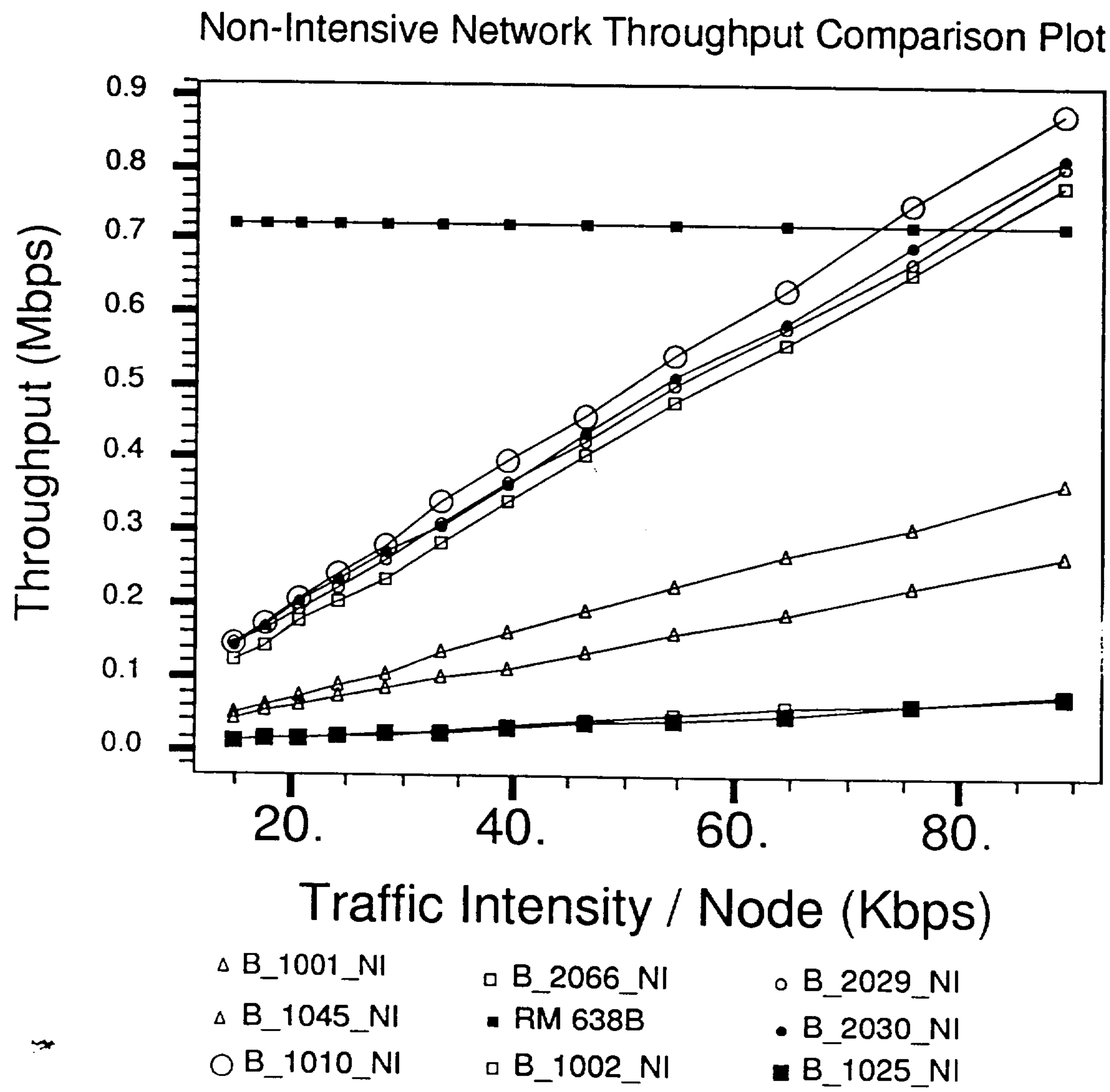


Figure 4.12 Non–Intensive network throughput plot for simulation time of 10 second

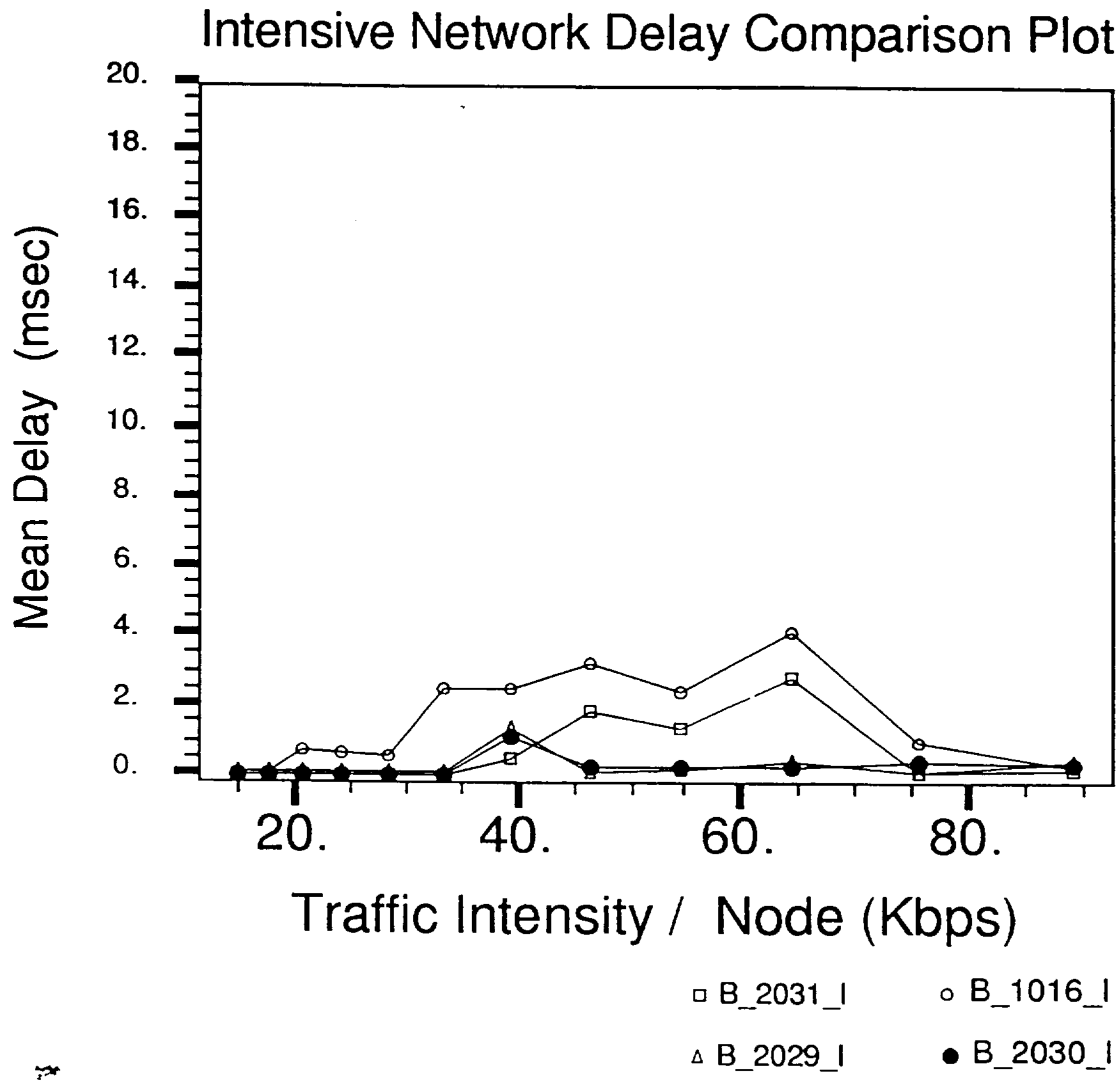


Figure 4.13 Intensive network delay plot for simulation time of 1 second

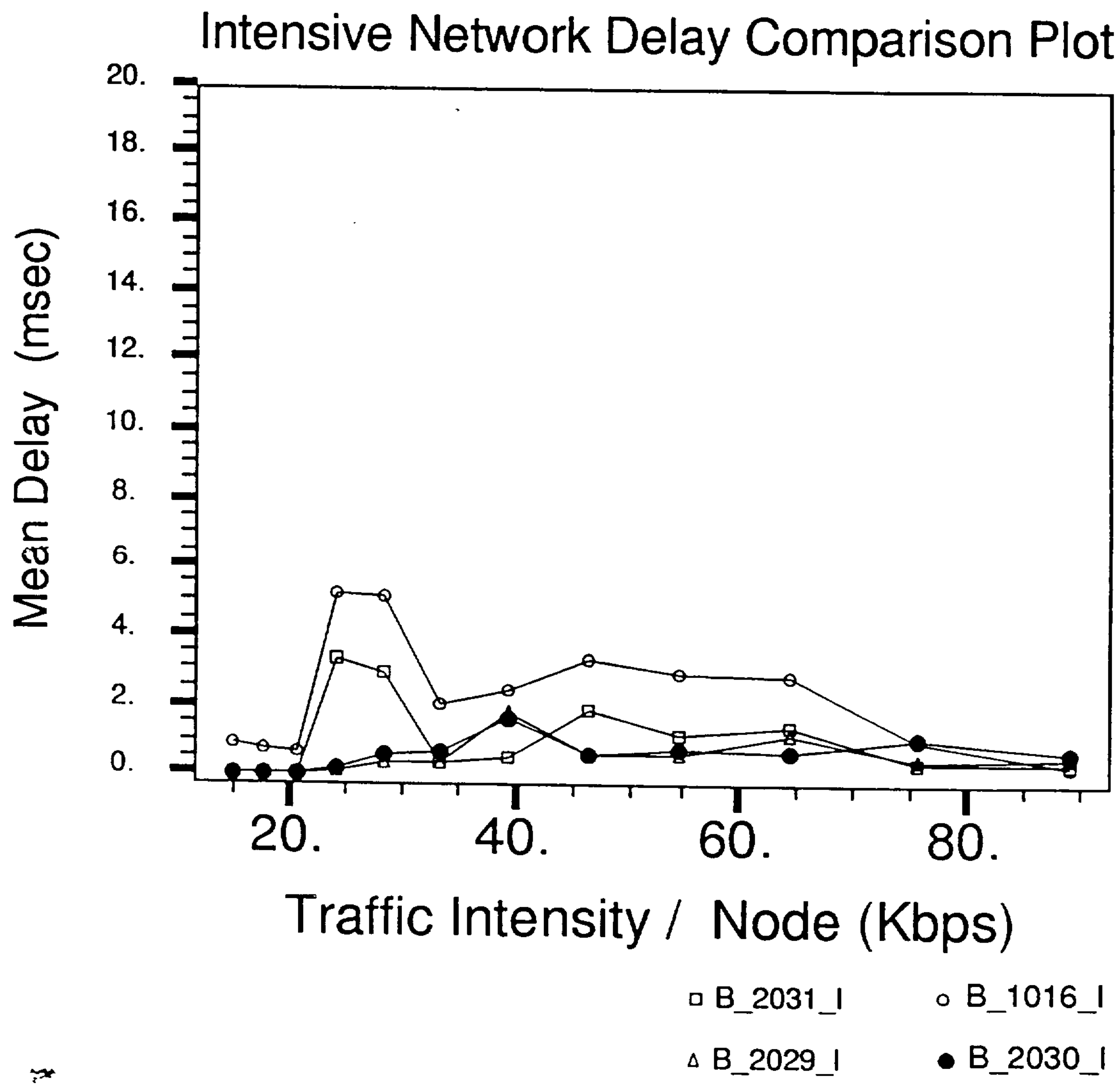


Figure 4.14 Intensive network delay plot for simulation time of 2 second

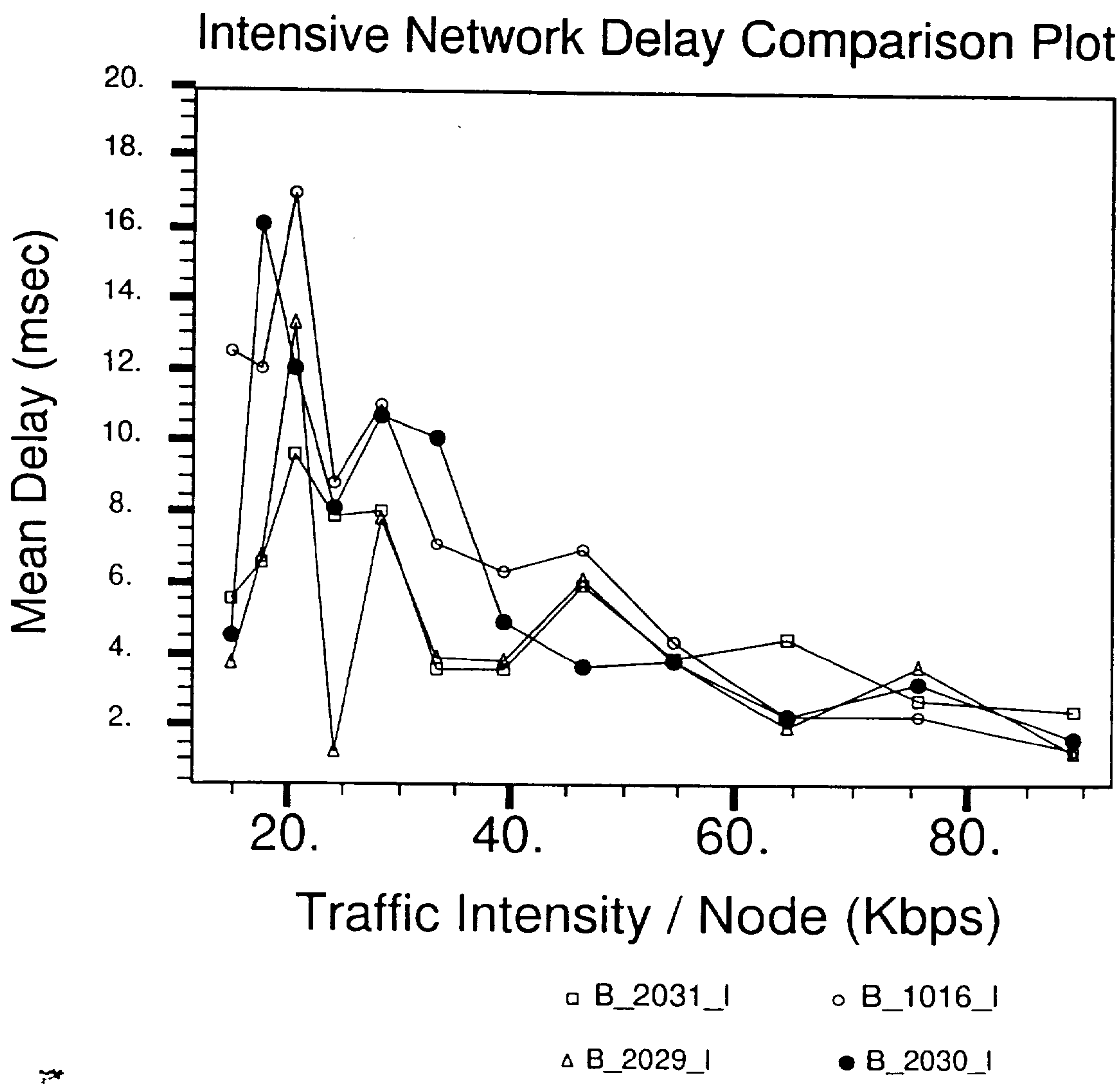


Figure 4.15 Intensive network delay plot for simulation time of 10 second

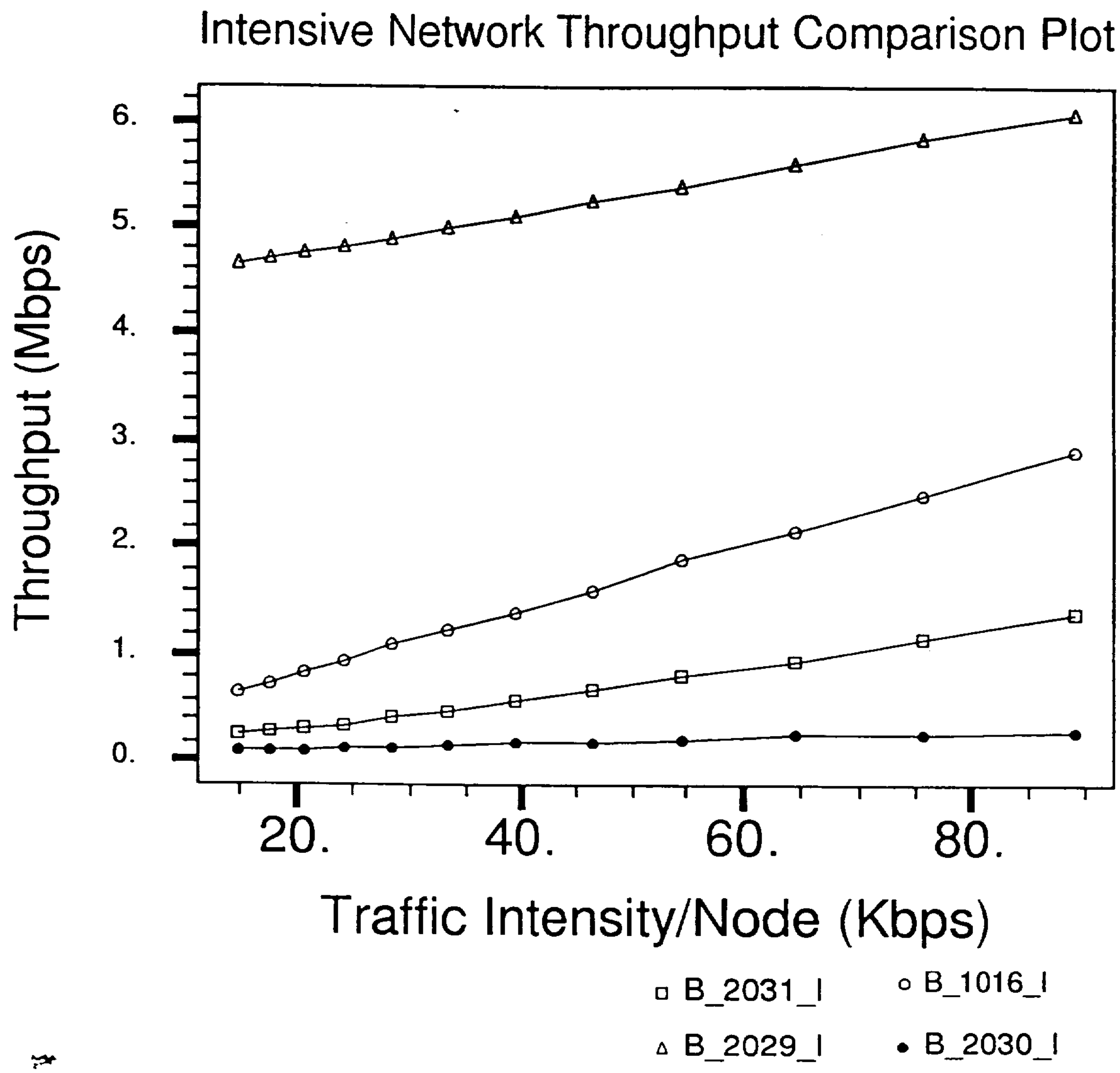


Figure 4.16 Intensive network throughput plot for simulation time of 1 second

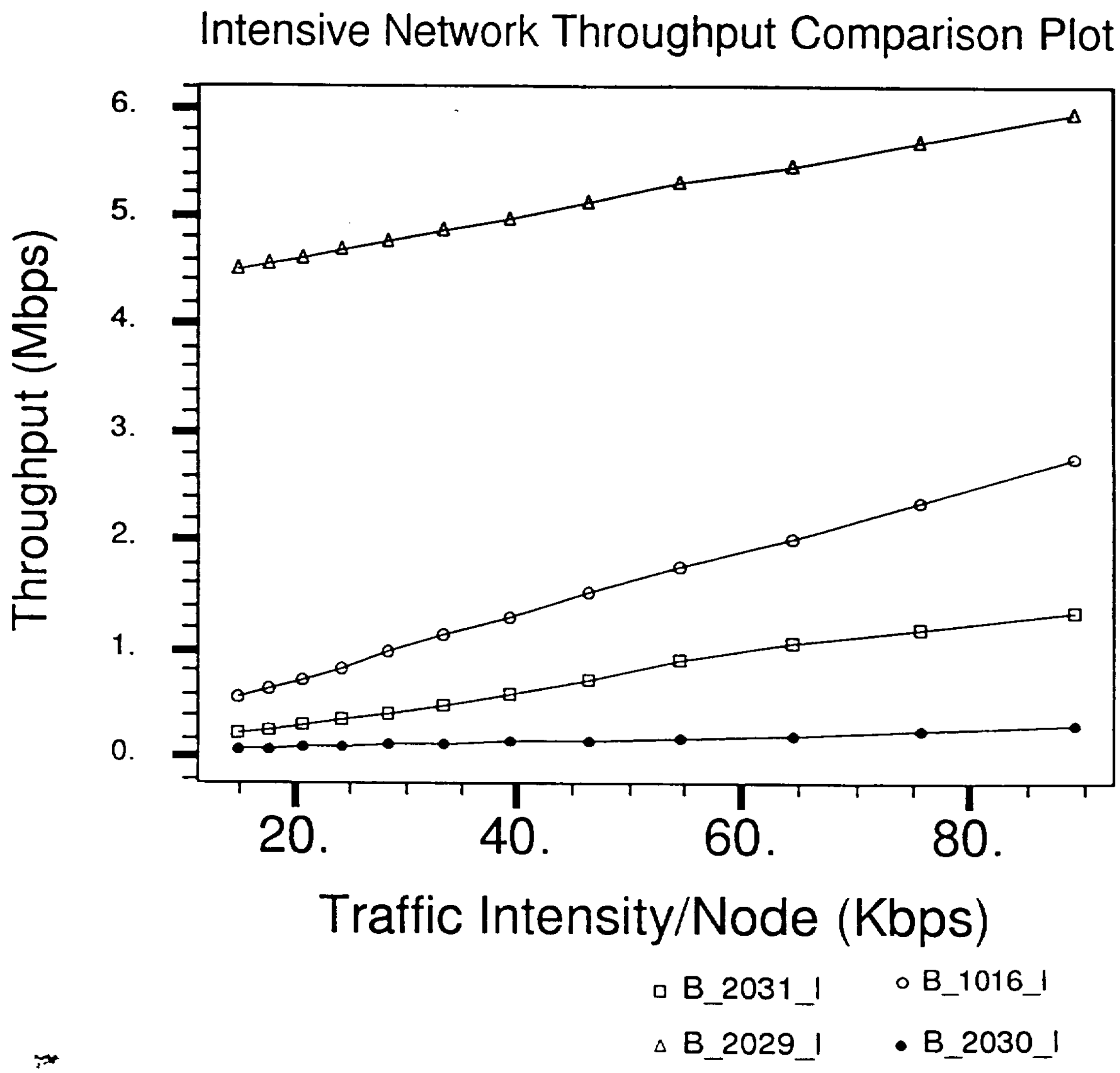


Figure 4.17 Intensive network throughput plot for simulation time of 2 second

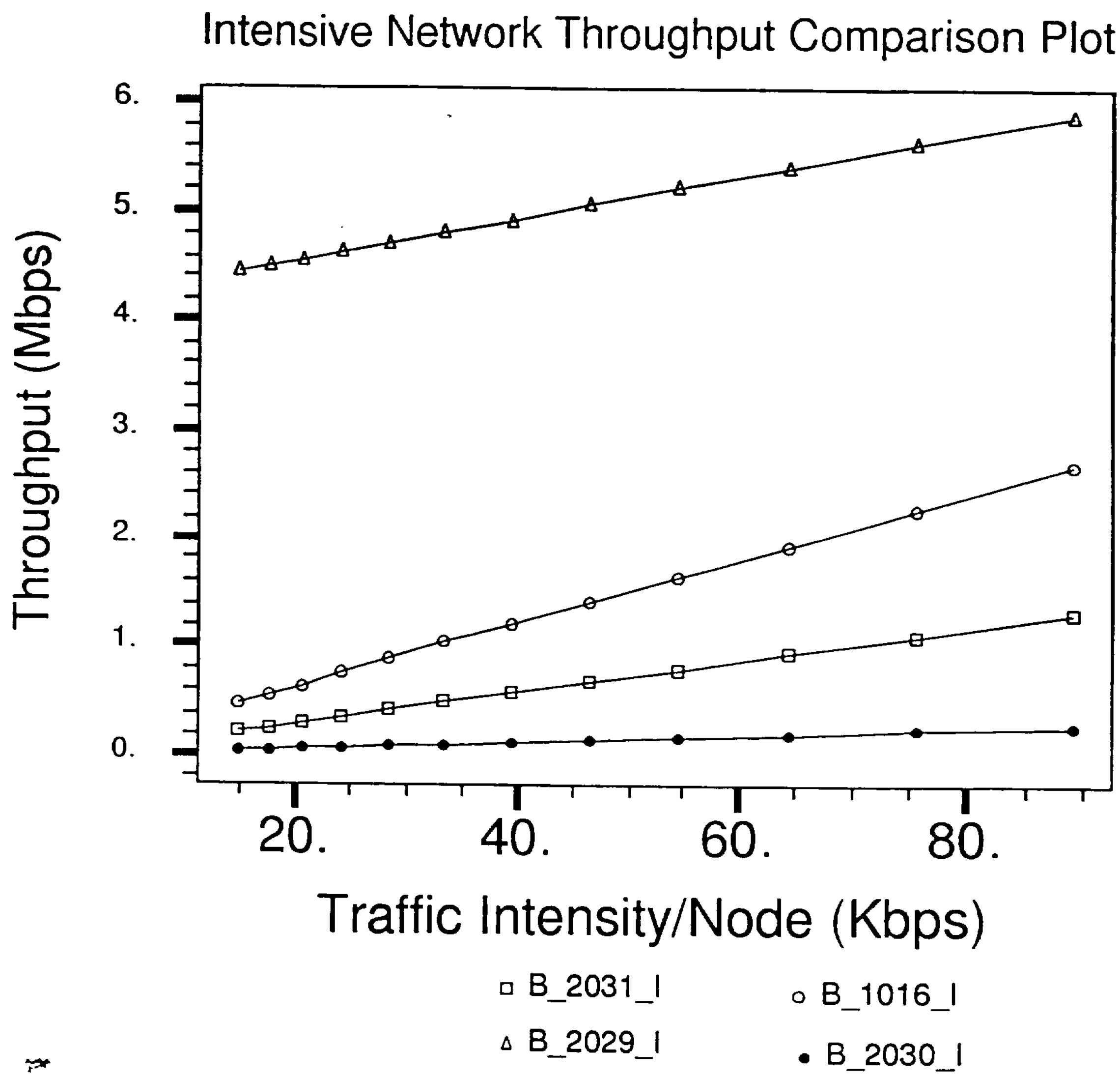


Figure 4.18 Intensive network throughput plot for simulation time of 10 second

# CHAPTER 5.0

# CONCLUSION

## 5.1 Discussion of the Simulation Results

This paper has introduced the basic operating characteristics of the network installed at the ASRM site located in Iuka, Mississippi. An overview of the network topology, communication protocols, and hardware devices was presented.

The main objective of the research was to model, simulate, and analyze the network to determine its performance. The two primary evaluation parameters used to judge the network performance were the throughput and the delay. The analysis of the ASRM network was simplified by using the commercial software BONeS. The ASRM simulation was built using several component from the BONeS library.

From the results obtained it can be concluded that, for the BIS devices the mean delay per packet increases as the offered traffic intensity increases, while for the OIS devices all the links show a knee at a particular traffic intensity. The knee in the curve corresponds to the buffer of the bridge becoming filled. Thus the buffer capacity of the bridges does appear to produce a bottleneck for the network. From the throughput plots it can also be seen that the BIS network is the most heavily loaded network. This can be attributed to the 400 Macintosh workstations connected to the BIS.

Among all the sub–networks the Intensive buildings experience the lowest delay. The FDDI backbone causes only a negligible delay compared to the other delay–causing factors considered in section 4.2.

The throughput for all the sub–networks increases linearly with the traffic intensity per node except for that of Gandalf terminal server in Room 638B. This is because the Gandalf terminal server is modeled as a constant traffic generator. The throughput plot for building 2029 intensive (B_2029_I) shows a very high value as compared to the throughput plots of other intensive buildings, because the workcell MTRQ, which is connected to it, has a data rate of 4.608 Mbps [3]. Thus it can be concluded that the workcell traffic does cause a significant effect on the workstation traffic.

## 5.2 Validation of the Simulation Model

Any simulation model must be validated before the results can be accepted. The BONeS modules developed for simulation were checked with the site engineers at ASRM for the validation of the modules.

## 5.3 Verification of the Simulation Results

The verification of the results was carried out using the throughput values obtained from the throughput plots. The delay plots obtained are highly stochastic in nature due to the heterogeneity of the network and the traffic flow. The BIS traffic is affected by the Non–Intensive workstation traffic and the Intensive workstation traffic is affected by the Non–Intensive workstation traffic and the workcell traffic.

From the definition of throughput we get the relation: throughput of a sub–network at a particular traffic intensity will be equal to the product of number of nodes in that sub–network and the traffic intensity. For the intensive network the throughput of the sub–network was calculated by adding the throughput of the each workcell in that sub–network to the total workstation throughput. The throughput value computed using this relationship was compared with the observed throughput value. A table of comparison between the simulation results and the theoritical values is presented below. The table shows that the simulation results agree with the calculated values.

Table 5.1 Verification table for the BIS devices

| Link | No of Nodes | Traffic Intensity (Kbps) | Through-put cal-culated (Mbps) | Throughput observed (Mbps) | | |
|---|---|---|---|---|---|---|
| | | | | 1 sec | 2 sec | 10 sec |
| MAC Network | 80 | 20 | 1.60 | 1.8 | 2.2 | 1.7 |
| | | 40 | 3.20 | 3.4 | 3.3 | 3.2 |
| | | 60 | 4.80 | 5.2 | 5.0 | 4.8 |
| | | 80 | 6.40 | 6.8 | 6.4 | 6.4 |
| Printer Network | 56 | 20 | 1.12 | 1.5 | 1.2 | 1.2 |
| | | 40 | 2.24 | 2.4 | 2.4 | 2.4 |
| | | 60 | 3.36 | 3.6 | 3.5 | 3.4 |
| | | 80 | 4.48 | 4.8 | 4.6 | 4.6 |
| B_2087_ NI | 14 | 20 | 0.28 | 0.4 | 0.3 | 0.3 |
| | | 40 | 0.56 | 0.6 | 0.6 | 0.6 |
| | | 60 | 0.84 | 1.0 | 0.9 | 0.9 |
| | | 80 | 1.12 | 1.2 | 1.2 | 1.2 |
| RM 507 | 57 | 20 | 1.14 | 1.5 | 1.4 | 1.2 |
| | | 40 | 2.28 | 2.5 | 2.4 | 2.4 |
| | | 60 | 3.42 | 3.8 | 3.6 | 3.5 |
| | | 80 | 4.56 | 4.8 | 4.6 | 4.6 |
| RM 638A | 80 | 20 | 1.60 | 1.8 | 1.8 | 1.7 |
| | | 40 | 3.20 | 3.4 | 3.2 | 3.2 |
| | | 60 | 4.80 | 5.2 | 4.8 | 4.8 |
| | | 80 | 6.40 | 6.8 | 6.4 | 6.4 |

Table 5.2 Verification table for the Non–Intensive network

| Link | No of Nodes | Traffic Intensity (Kbps) | Through-put calculated (Mbps) | Throughput observed (Mbps) | | |
|---|---|---|---|---|---|---|
| | | | | 1 sec | 2 sec | 10 sec |
| B_1001_ NI | 03 | 20 | 0.06 | 0.06 | 0.06 | 0.06 |
| | | 40 | 0.12 | 0.12 | 0.12 | 0.12 |
| | | 60 | 0.18 | 0.18 | 0.17 | 0.18 |
| | | 80 | 0.24 | 0.22 | 0.24 | 0.24 |
| B_1045_ NI | 04 | 20 | 0.08 | 0.08 | 0.08 | 0.08 |
| | | 40 | 0.16 | 0.16 | 0.16 | 0.16 |
| | | 60 | 0.24 | 0.23 | 0.21 | 0.24 |
| | | 80 | 0.32 | 0.32 | 0.30 | 0.32 |
| B_1010_ NI | 10 | 20 | 0.20 | 0.30 | 0.26 | 0.20 |
| | | 40 | 0.40 | 0.52 | 0.42 | 0.40 |
| | | 60 | 0.60 | 0.66 | 0.60 | 0.60 |
| | | 80 | 0.80 | 0.86 | 0.80 | 0.80 |
| B_2066_ NI | 04 | 20 | 0.08 | 0.20 | 0.16 | 0.16 |
| | | 40 | 0.16 | 0.34 | 0.34 | 0.34 |
| | | 60 | 0.24 | 0.54 | 0.50 | 0.52 |
| | | 80 | 0.32 | 0.64 | 0.68 | 0.68 |
| RM 638B | 01 | 20 | 0.72 | 0.82 | 0.72 | 0.72 |
| | | 40 | 0.72 | 0.82 | 0.72 | 0.72 |
| | | 60 | 0.72 | 0.82 | 0.72 | 0.72 |
| | | 80 | 0.72 | 0.82 | 0.72 | 0.72 |
| B_1002_ NI | 01 | 20 | 0.02 | 0.03 | 0.02 | 0.02 |
| | | 40 | 0.04 | 0.04 | 0.04 | 0.04 |
| | | 60 | 0.06 | 0.05 | 0.06 | 0.06 |
| | | 80 | 0.08 | 0.08 | 0.08 | 0.08 |
| B_2029_ NI | 09 | 20 | 0.18 | 0.28 | 0.22 | 0.18 |
| | | 40 | 0.36 | 0.44 | 0.42 | 0.36 |
| | | 60 | 0.54 | 0.62 | 0.60 | 0.55 |
| | | 80 | 0.72 | 0.84 | 0.80 | 0.72 |

Table 5.2 (continued)

| Link | No of Nodes | Traffic Intensity (Kbps) | Through-put cal-culated (Mbps) | Throughput observed (Mbps) | | |
|---|---|---|---|---|---|---|
| | | | | 1 sec | 2 sec | 10 sec |
| B_2030_NI | 09 | 20 | 0.18 | 0.30 | 0.22 | 0.20 |
| | | 40 | 0.36 | 0.48 | 0.47 | 0.38 |
| | | 60 | 0.54 | 0.68 | 0.62 | 0.56 |
| | | 80 | 0.72 | 0.88 | 0.80 | 0.74 |
| B_1025_NI | 01 | 20 | 0.02 | 0.03 | 0.02 | 0.02 |
| | | 40 | 0.04 | 0.04 | 0.04 | 0.04 |
| | | 60 | 0.06 | 0.05 | 0.06 | 0.07 |
| | | 80 | 0.08 | 0.07 | 0.08 | 0.08 |

Table 5.3 Verification table for the Intensive network

| Link | No of Nodes | Traffic Intensity (Kbps) | Through-put cal-culated (Mbps) | Throughput observed (Mbps) | | |
|---|---|---|---|---|---|---|
| B_2031_I | 15 | 20 | 0.30 | 0.30 | 0.30 | 0.30 |
| | | 40 | 0.60 | 0.60 | 0.60 | 0.60 |
| | | 60 | 0.90 | 0.80 | 1.00 | 0.90 |
| | | 80 | 1.20 | 1.20 | 1.20 | 1.20 |
| B_2029_I | 24 | 20 | 0.48 | 4.80 | 4.60 | 4.60 |
| | | 40 | 0.96 | 5.10 | 5.00 | 5.00 |
| | | 60 | 1.44 | 5.40 | 5.40 | 5.40 |
| | | 80 | 1.92 | 5.80 | 5.80 | 5.80 |
| B_1016_I | 43 | 20 | 0.86 | 0.90 | 0.70 | 0.70 |
| | | 40 | 1.72 | 1.40 | 1.40 | 1.40 |
| | | 60 | 2.58 | 2.00 | 2.00 | 1.80 |
| | | 80 | 3.44 | 2.60 | 2.40 | 2.50 |
| B_2030_I | 09 | 20 | 0.18 | 0.20 | 0.15 | 0.10 |
| | | 40 | 0.36 | 0.30 | 0.30 | 0.30 |
| | | 60 | 0.54 | 0.30 | 0.40 | 0.40 |
| | | 80 | 0.72 | 0.30 | 0.60 | 0.50 |

5.4 Recommendations for Further Study

Not intended to be a complete analysis, this thesis provides the basic concepts by which the ASRM network was evaluated. A more detailed analysis of the network can be accomplished. Parameters such as traffic intensity, packet size, and response times can be varied in order to gain a more accurate and diverse analysis of network performance. For example a simulation can be run with the packet length set to the worst–case condition of 64 bytes. However, this also means that building a simulation can be a complex task and the actual time to do the simulations can be very long.

At this point in time, the Cabletron hubs used to connect the individual networks have been modeled in BONeS as constant delays. A detailed analysis of the Cabletron hubs can be performed. This analysis will allow a more precise and accurate model for the BONeS simulator to be built. In so doing, the results produced by the computer simulation can approach a higher degree of accuracy.

It would be also interesting to see the effect of a different traffic pattern from the BIS devices on the Intensive and Non–Intensive networks. This analysis would help for example in estimating the effect on the whole network due to increasing the number of BIS Macintosh machines. The study of the effect of workcell–to–ASC traffic on Intensive and Non–Intensive workstations would be useful in drawing some important conclusions. Lastly analysis of the traffic flow external to the ASRM network would be useful to observe its effect on the BIS hub.

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[3] Meeting at RUST, Birmingham, Alabama on 08/25/92 attended by Dale Scruggs (RUST), Kirk Weiss (RUST), Walter Robinson (NASA), Robert Moorhead (MSU), and Ravi Nirgudkar (MSU).

[4] Handouts related to the workcell connectivity received at the 08/25/92 meeting.

[5] Teleconference, on 10/15/92 attended by John Donaldsen (LMSC), Merlin Hill (AAD), Dale Scruggs (RUST), Kirk Weiss (RUST), Walter Robinson (NASA), Robert Moorhead (MSU), and Ravi Nirgudkar (MSU).

[6] Teleconference, on 01/19/93, attended by Walter Robinson (NASA), Doug Thomas (NASA), Phil Kelley (LMSC), John Donaldsen (LMSC), Ted Roberts (LMSC), Dale Scruggs (RUST), Tom Reed (RUST), Robert Moorhead (MSU), Wayne Smith (MSU), and Ravi Nirgudkar (MSU).

[7] Meeting at ASRM site, Iuka, Mississippi on 04/08/93 attended by John Donaldsen (LMSC), Merlin Hill (AAD), Miles Martin (LMSC), Walter Robinson (NASA), Robert Moorhead (MSU), Wayne Smith (MSU), and Ravi Nirgudkar (MSU).

[8] FAX received from Walter Robinson, NASA, on 09/01/92.

[9] FAX received from Kyle Maus, ASRM, on 10/05/92.

[10] FAX received from Kirk Weiss, RUST, on 10/14/92.

[11] FAX received from Dale Scruggs, RUST, on 11/24/92.

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[25] Fiber Distributed Data Interface (FDDI) Technical Overview, Cabletron Systems, Inc., April 6, 1992.

# APPENDIX A

# BONeS MODULES

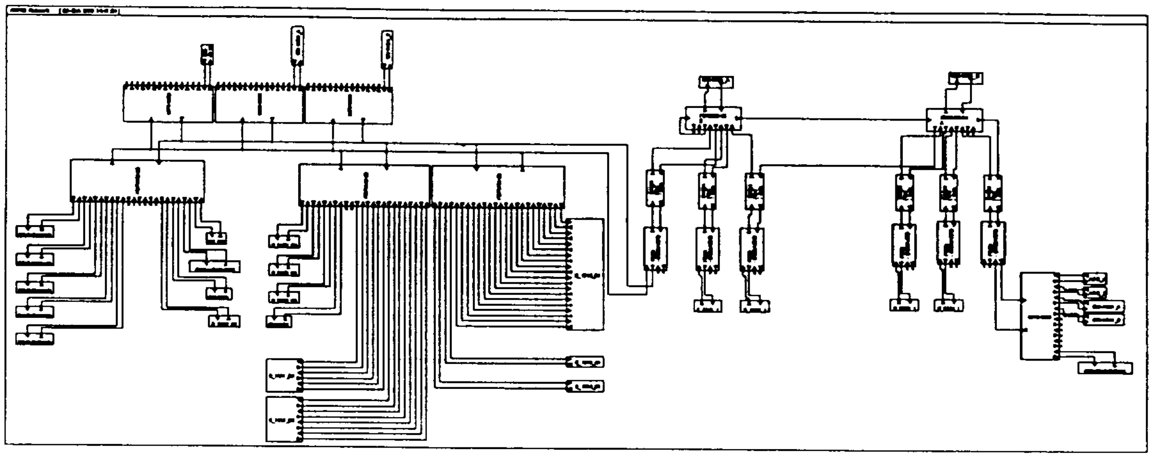

Figure A.1 ASRM network Model

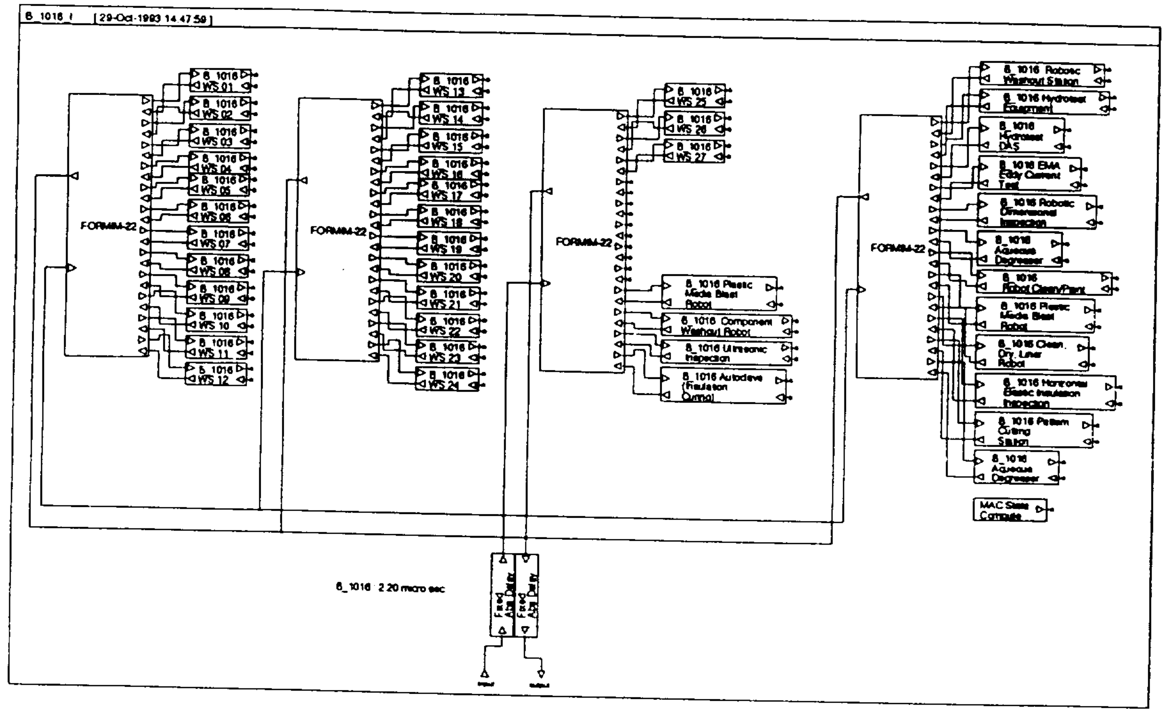

Figure A.2 Intensive building 1016 Model

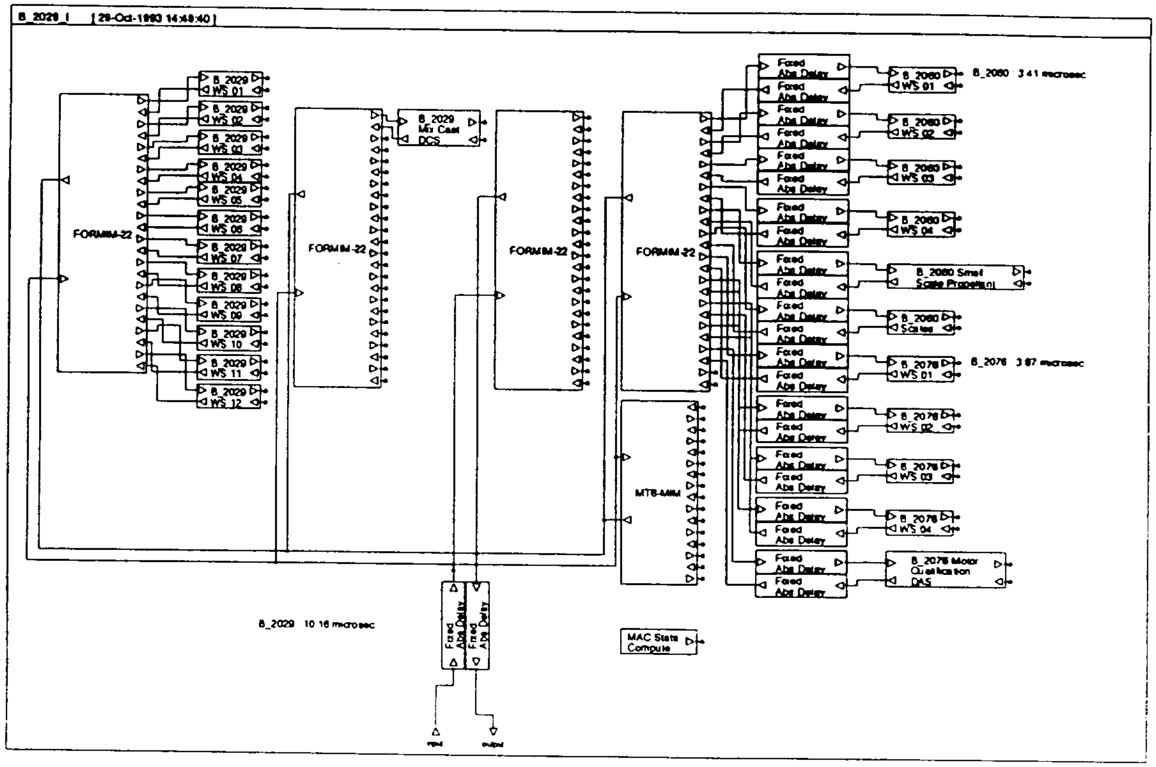

Figure A.3 Intensive building 2029 Model

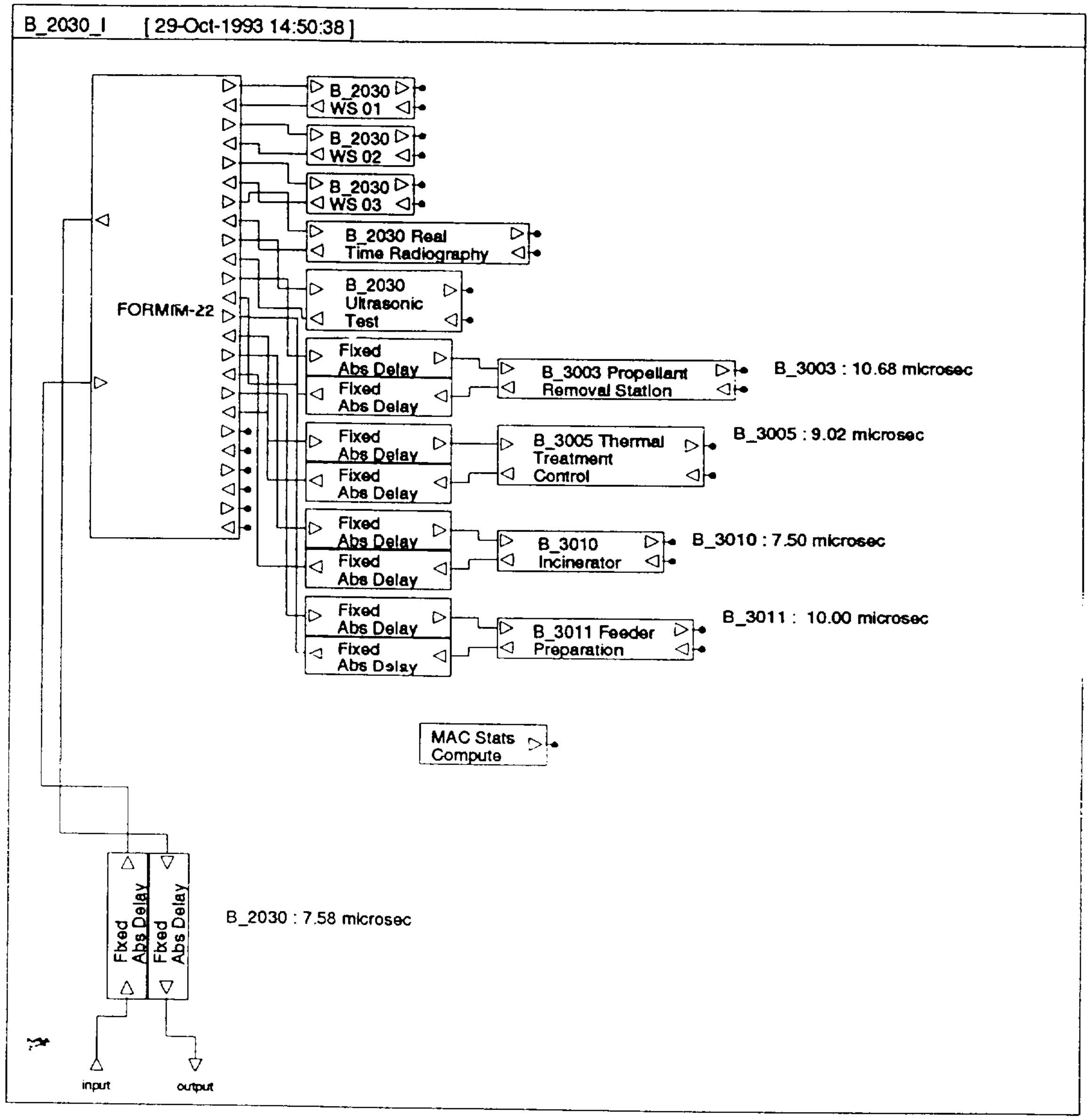


Figure A.4 Intensive building 2030 Model

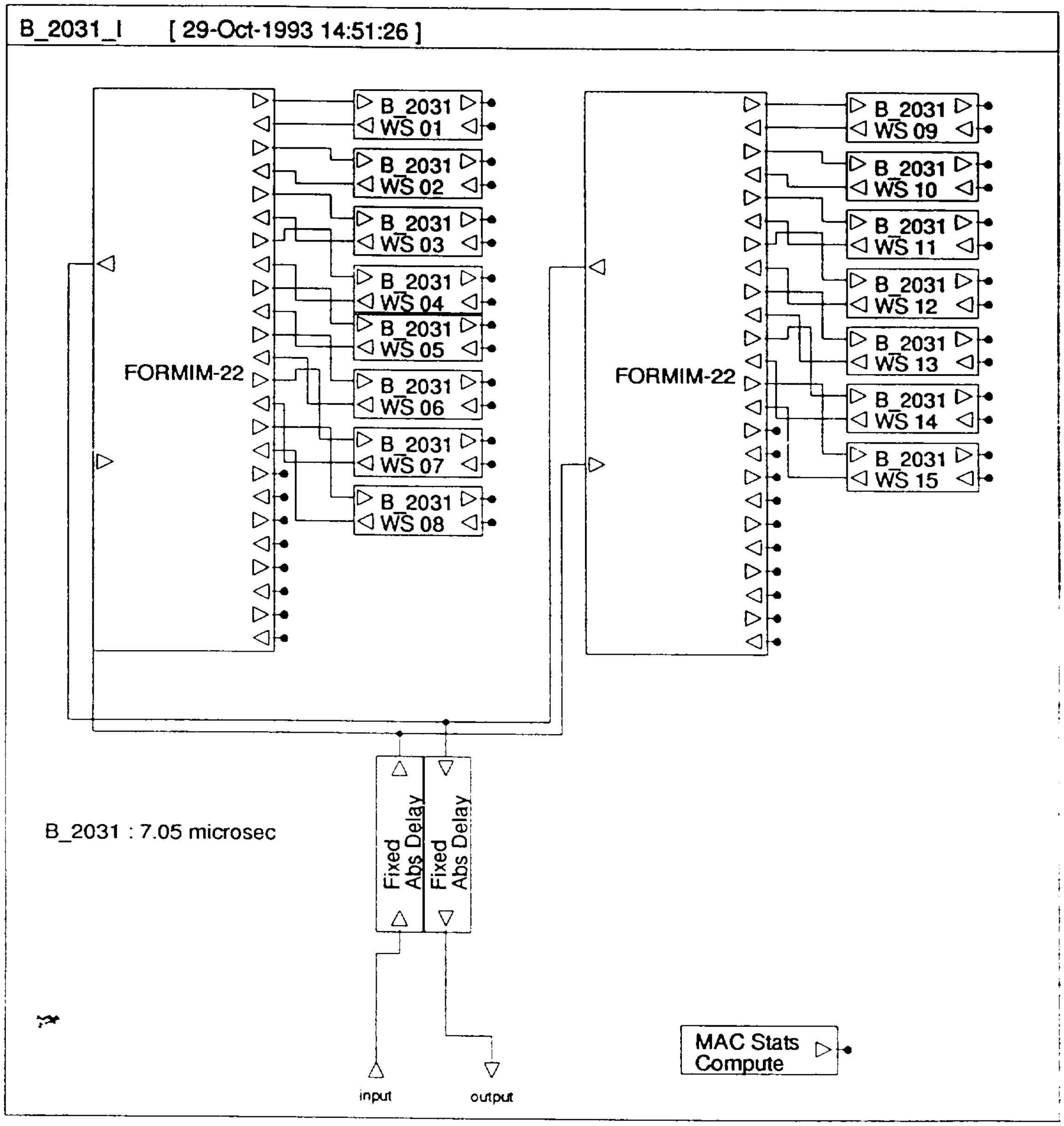


Figure A.5 Intensive building 2031 Model

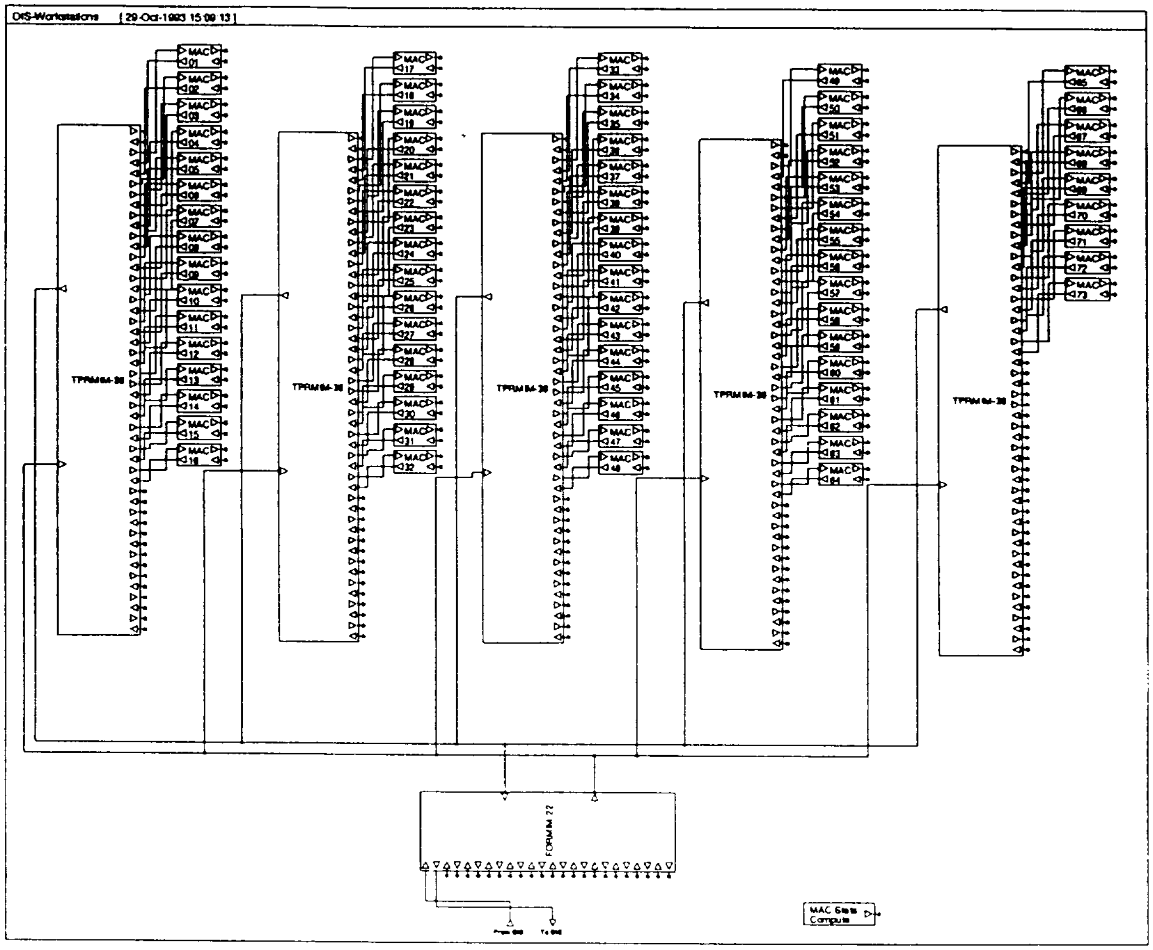

Figure A.6 73 OIS Workstations Model

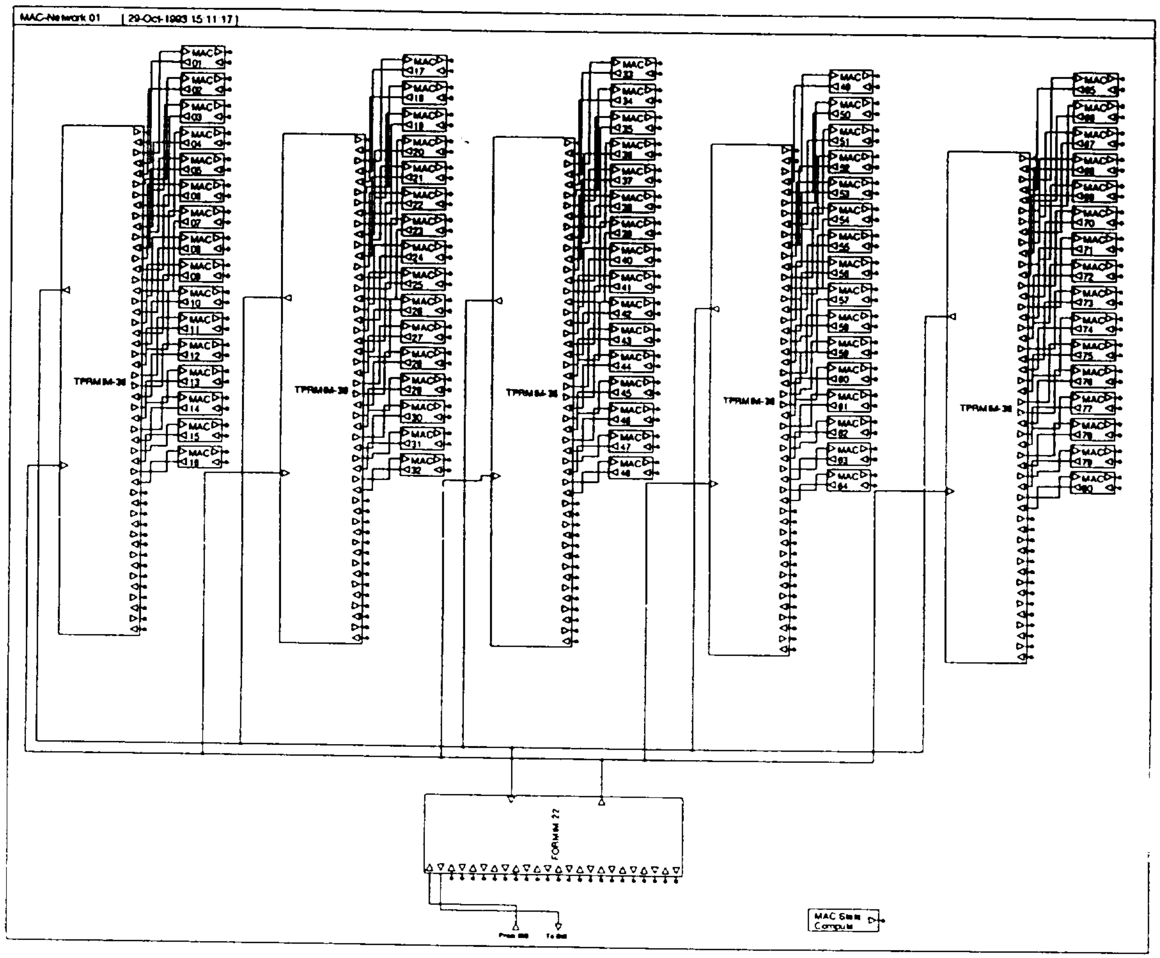

Figure A.7 Macintosh network model

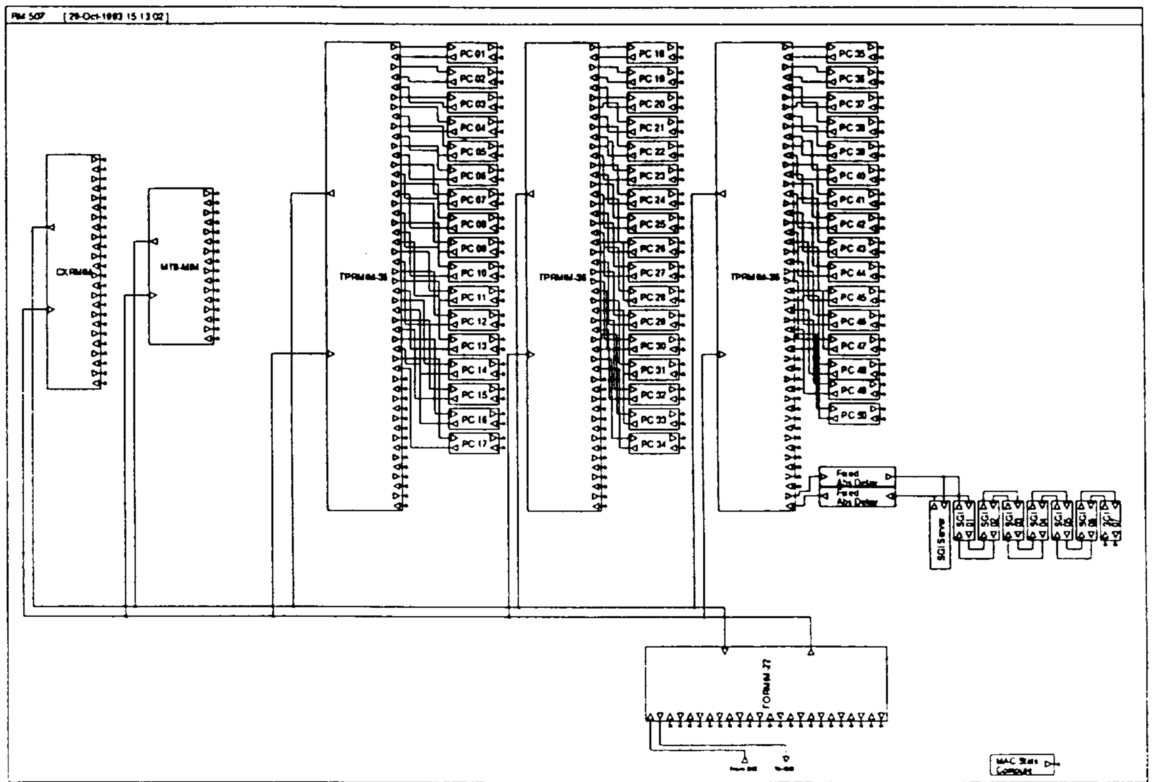

Figure A.8 Room 507 Model

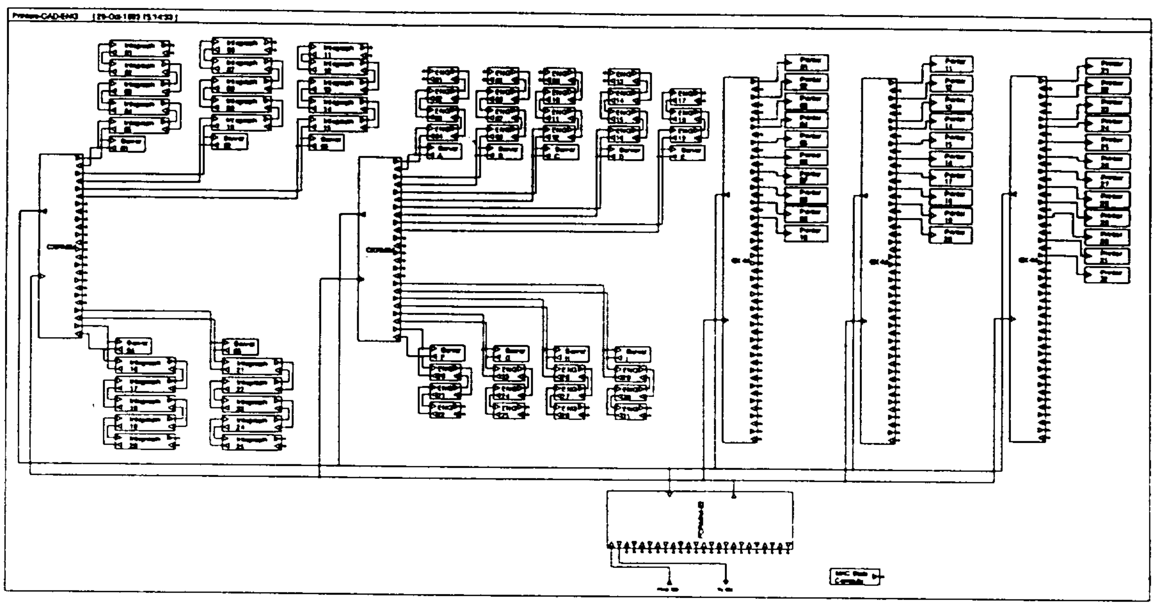

Figure A.9 Printer room Model

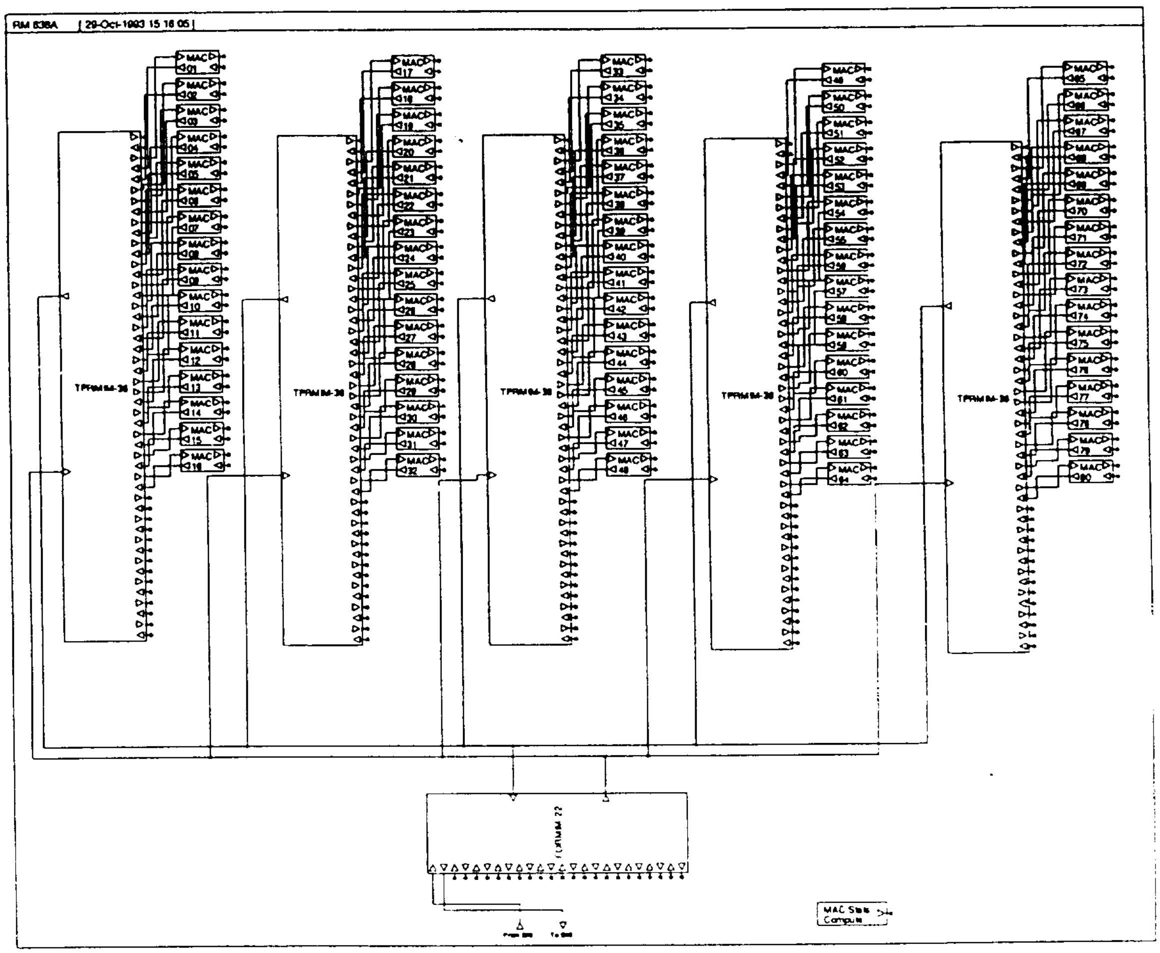

Figure A.10 Room 638A Model

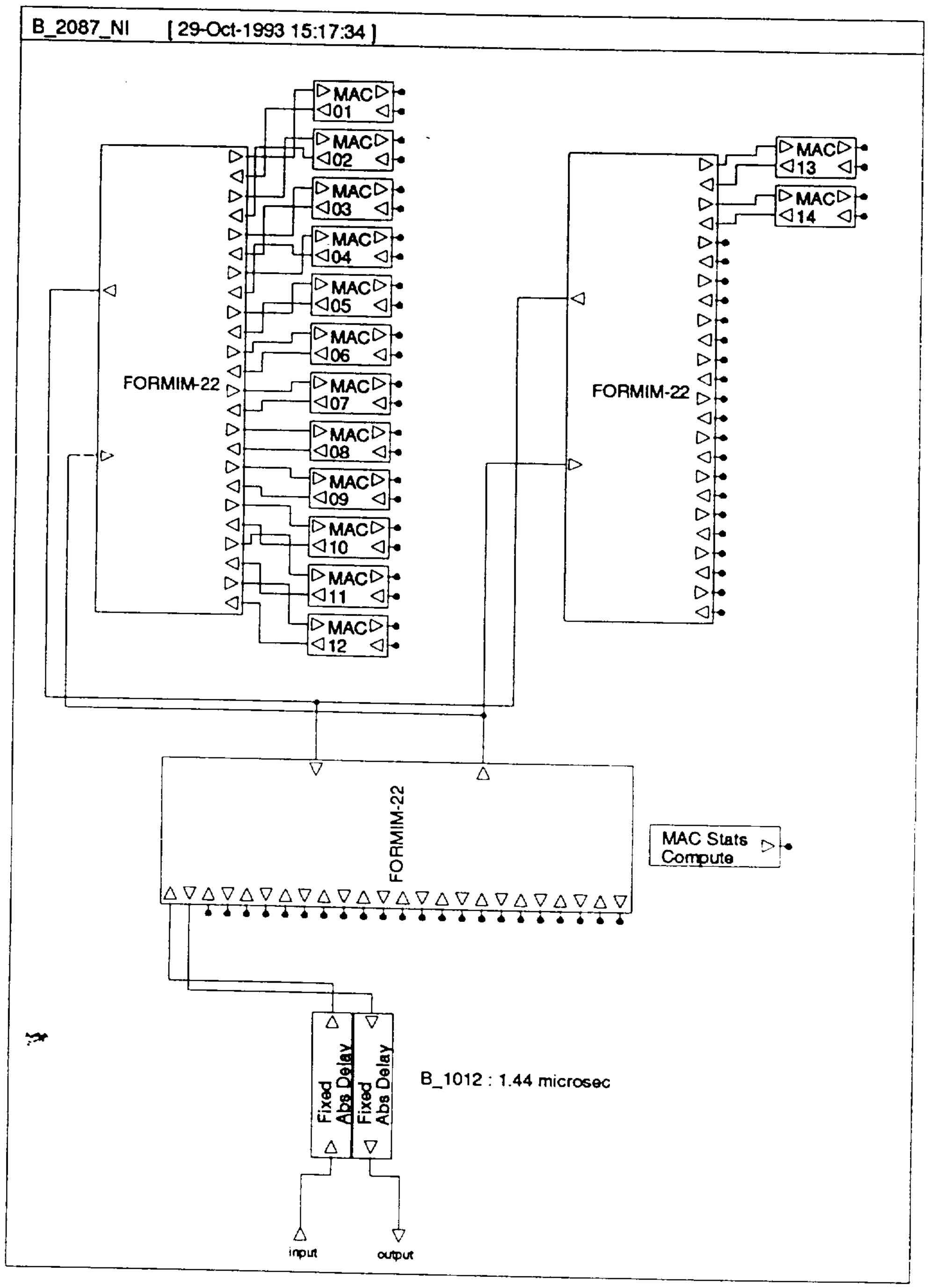


Figure A.11 Non–Intensive building 2087 Model

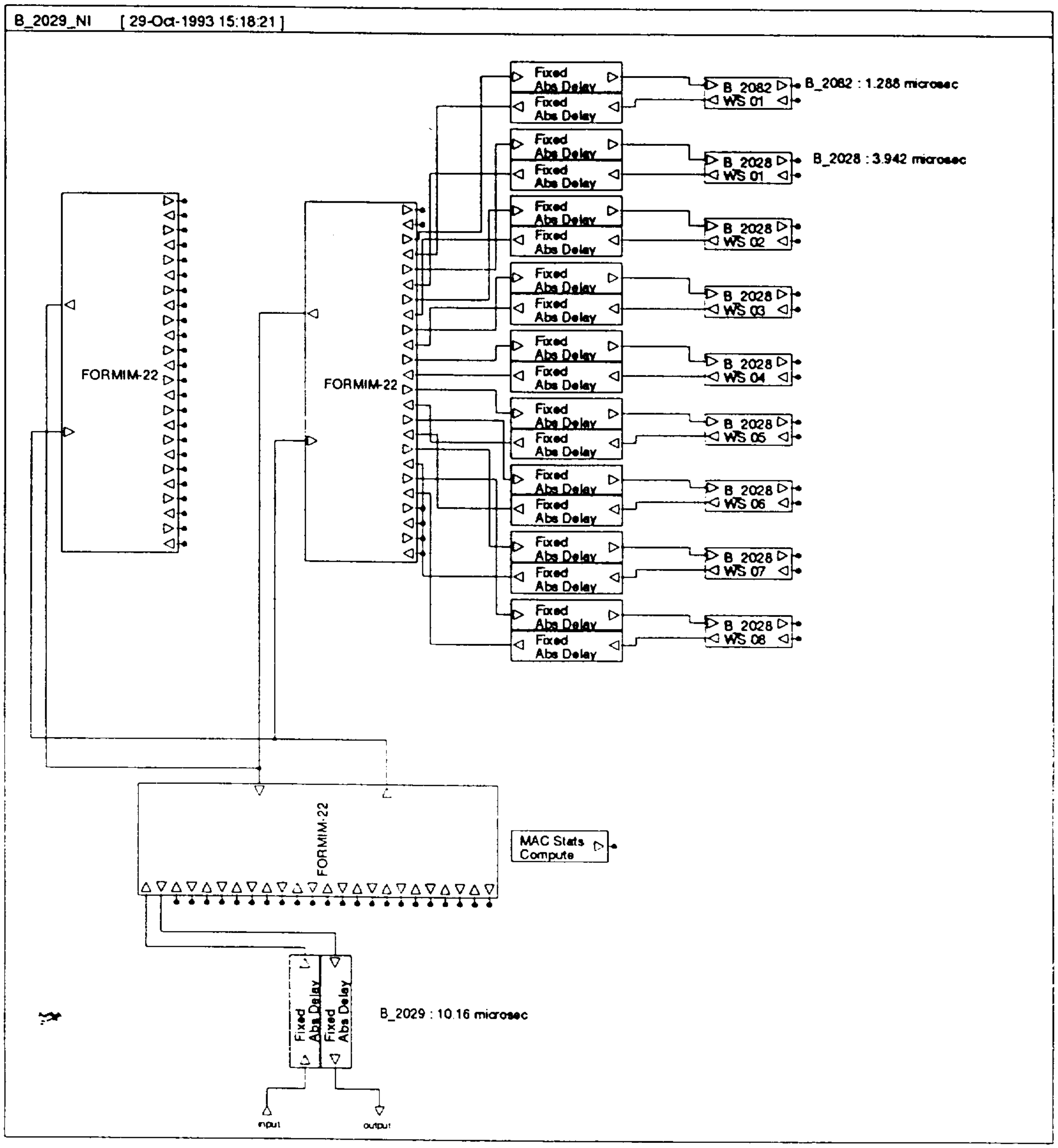


Figure A.12 Non–Intensive building 2029 Model

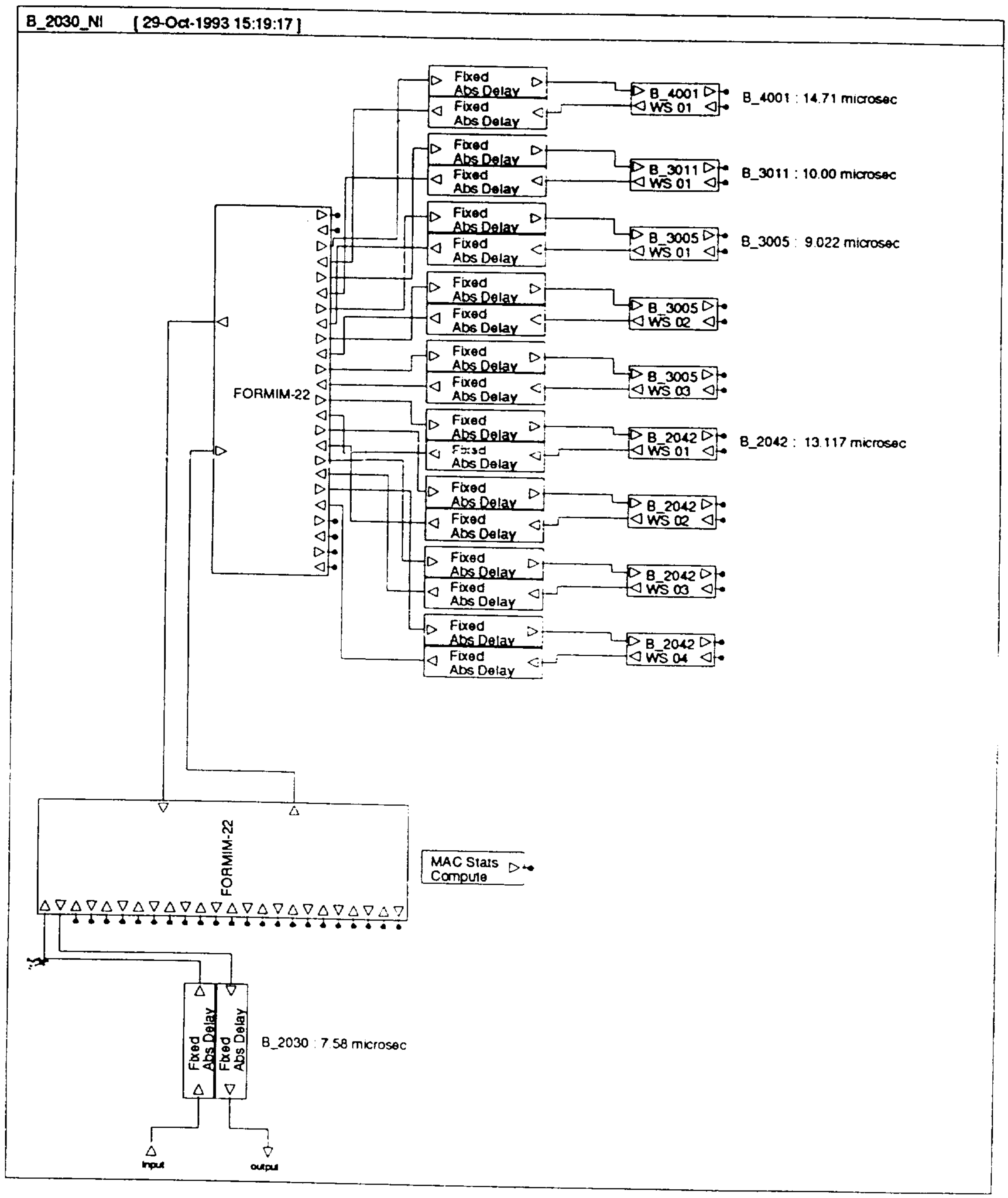


Figure A.13 Non–Intensive building 2030 Model

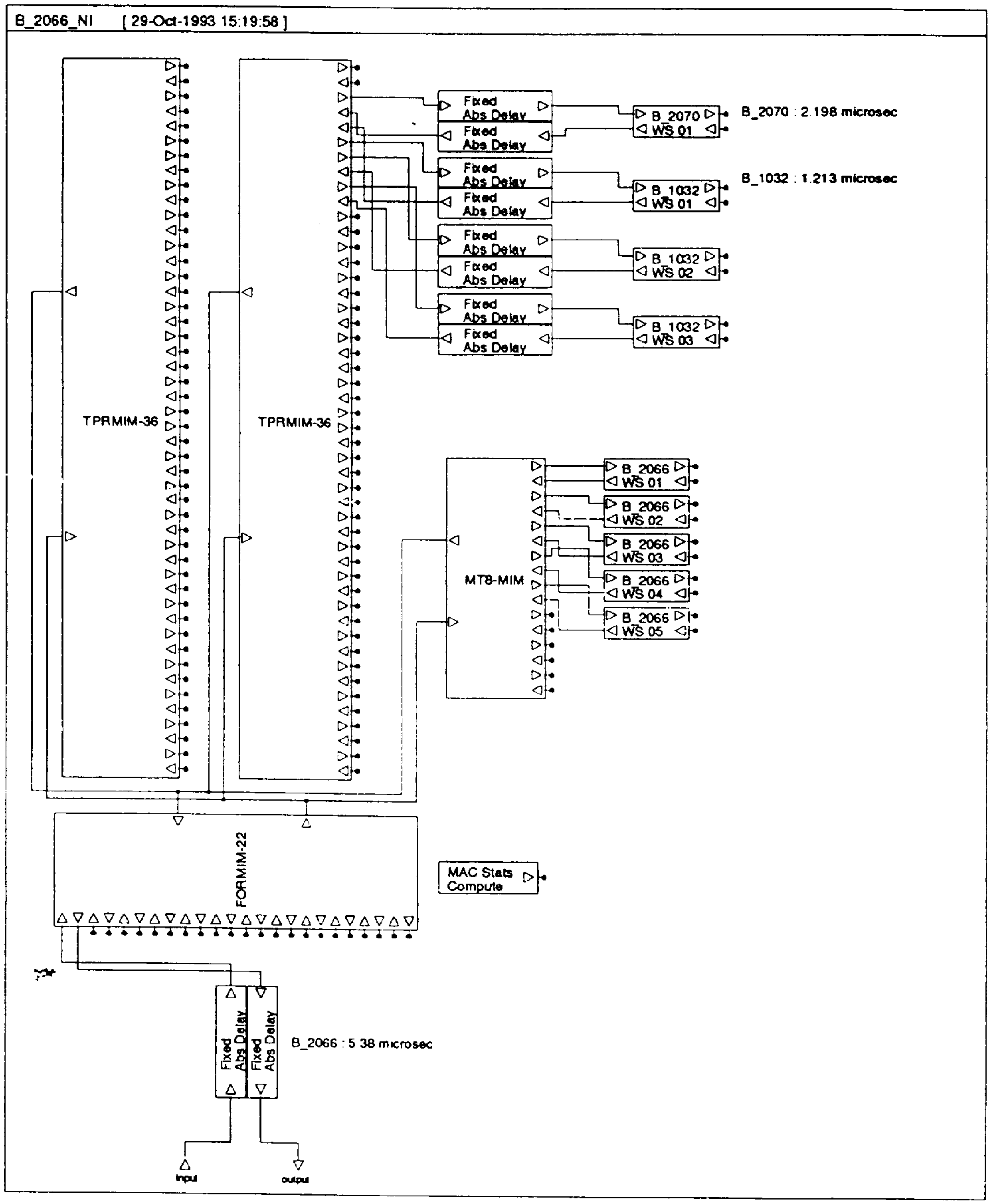


Figure A.14 Non–Intensive building 2066 Model

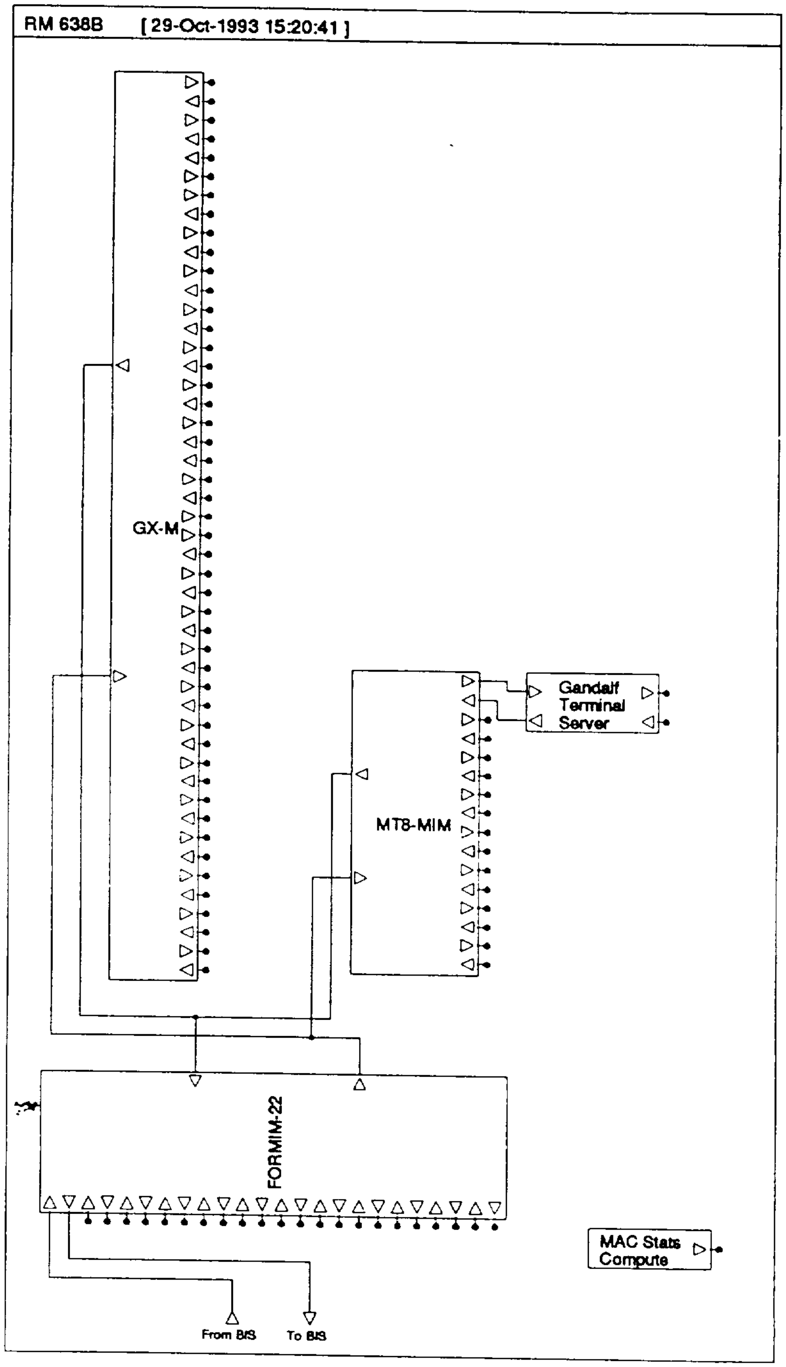


Figure A.15 Room 638B Model

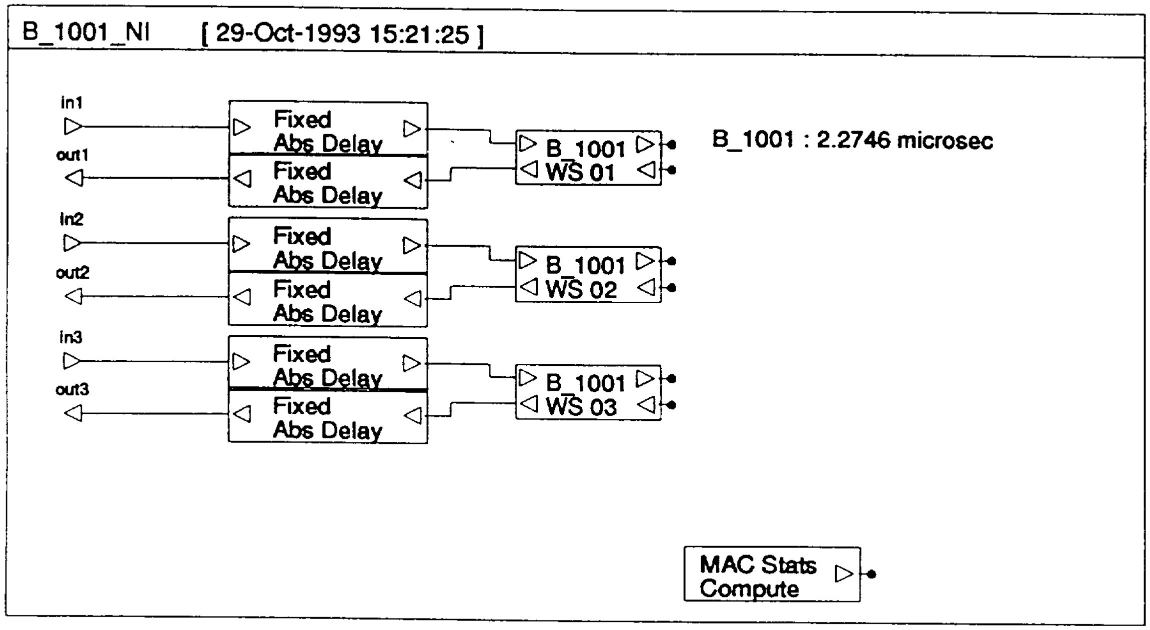


Figure A.16 Non–Intensive building 1001 Model

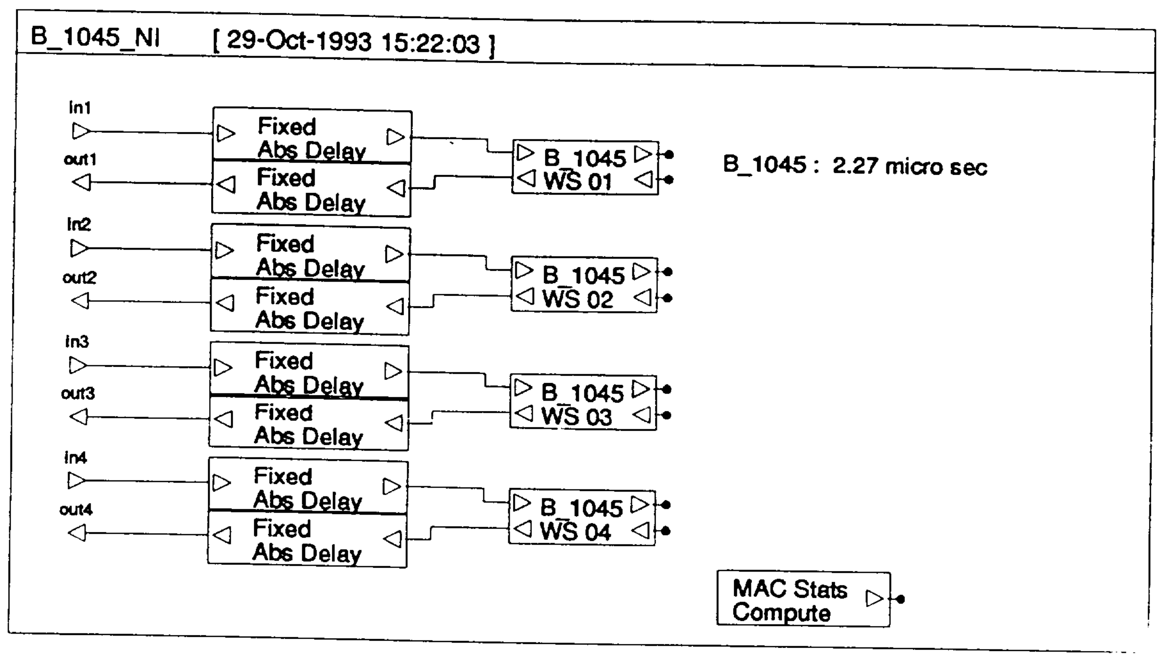


Figure A.17 Non–Intensive building 1045 Model

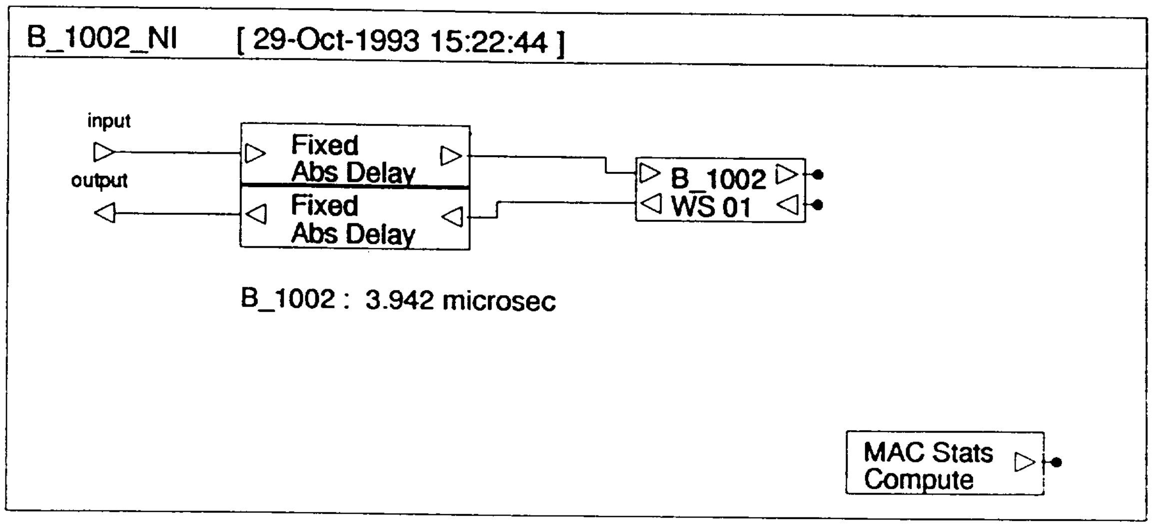


Figure A.18 Non–Intensive building 1002 Model

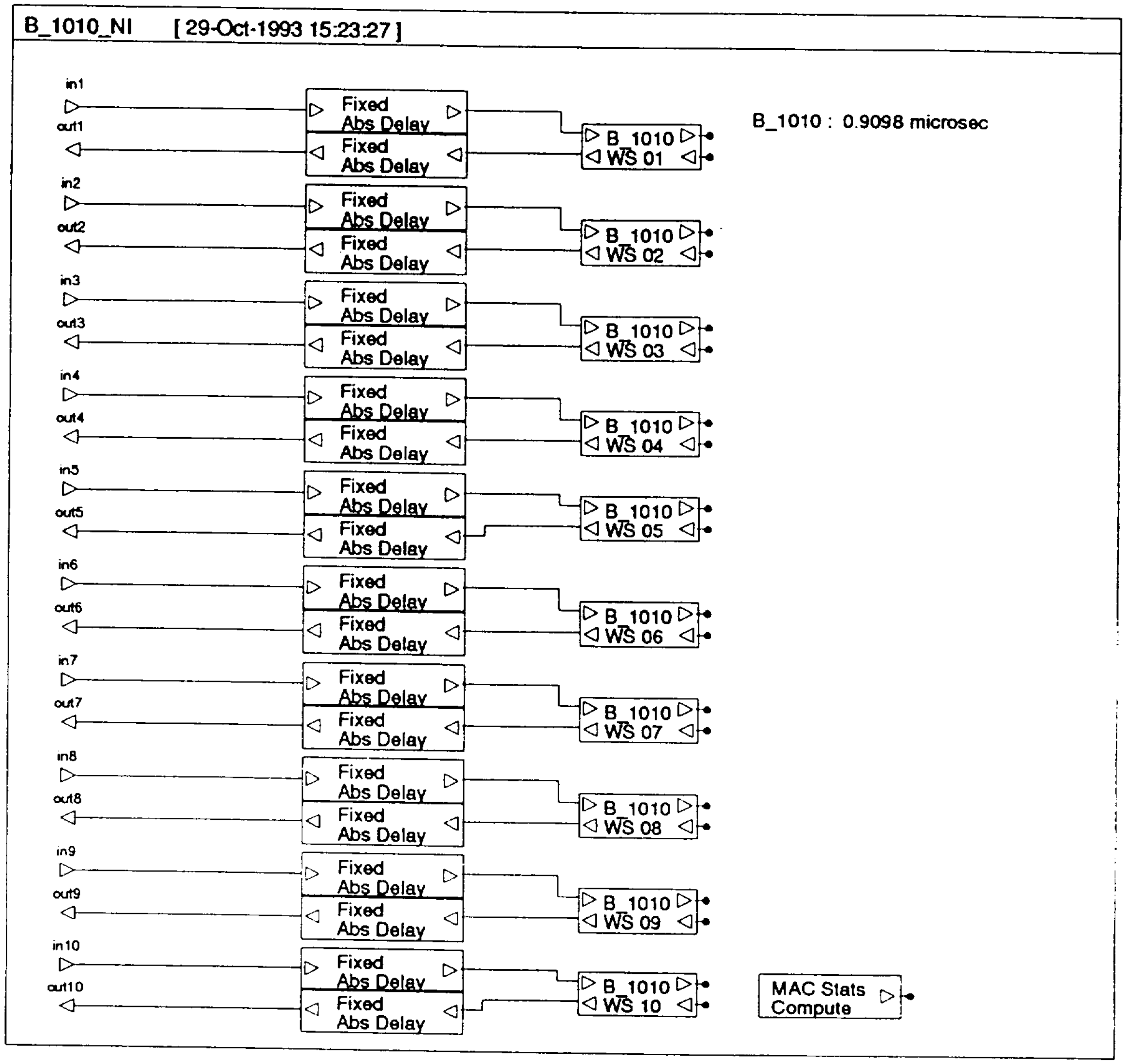


Figure A.19 Non–Intensive building 1010 Model

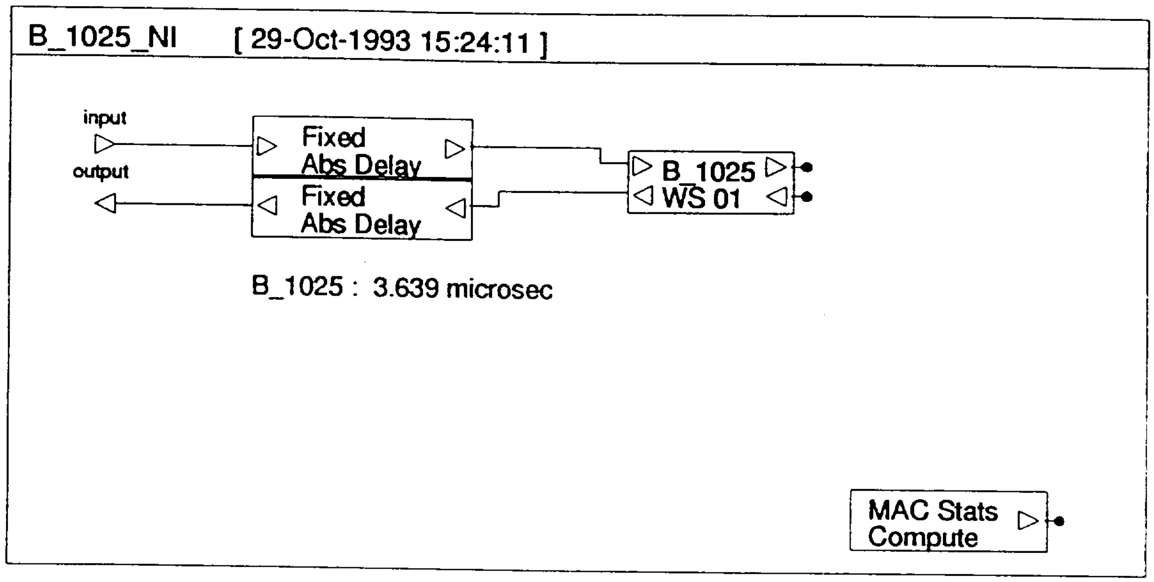


Figure A.20 Non–Intensive building 1025 Model

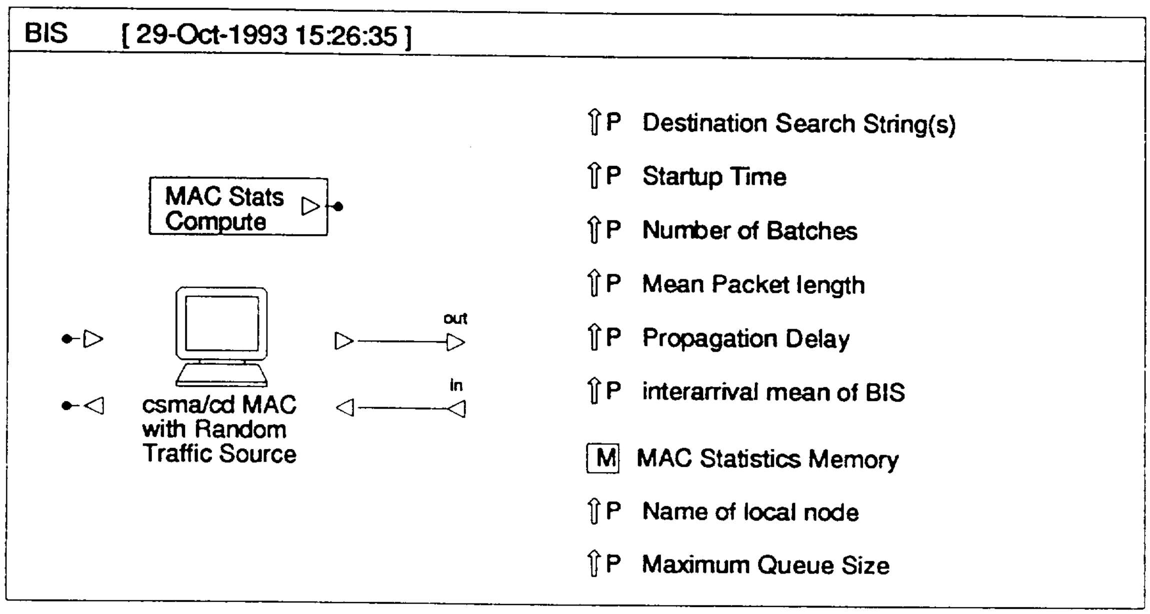


Figure A.21 BIS Model

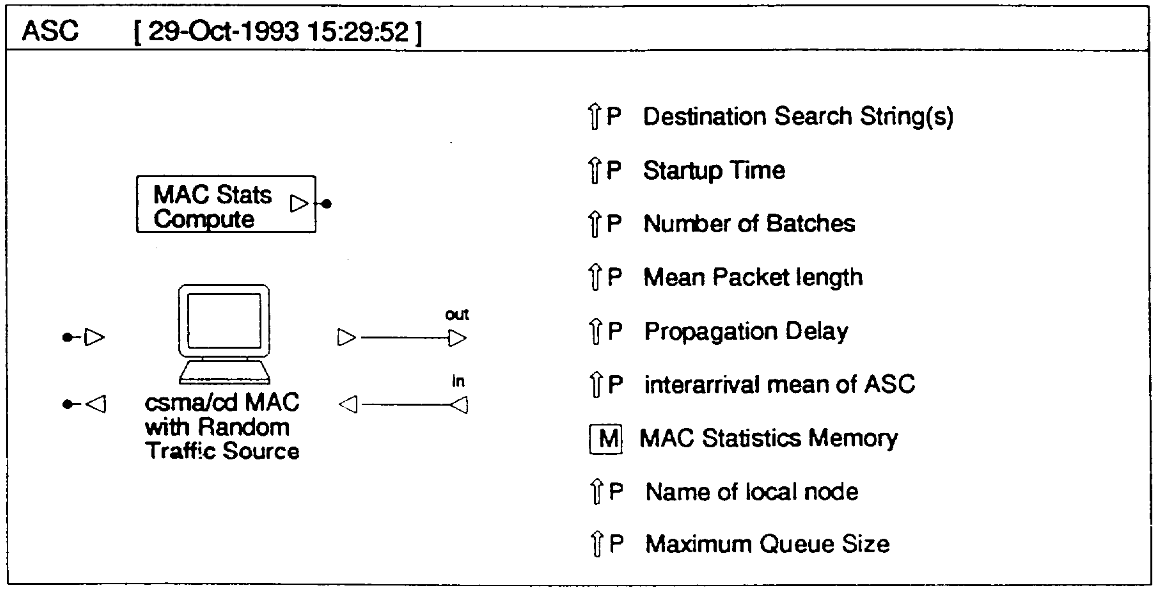


Figure A.22 ASC Model

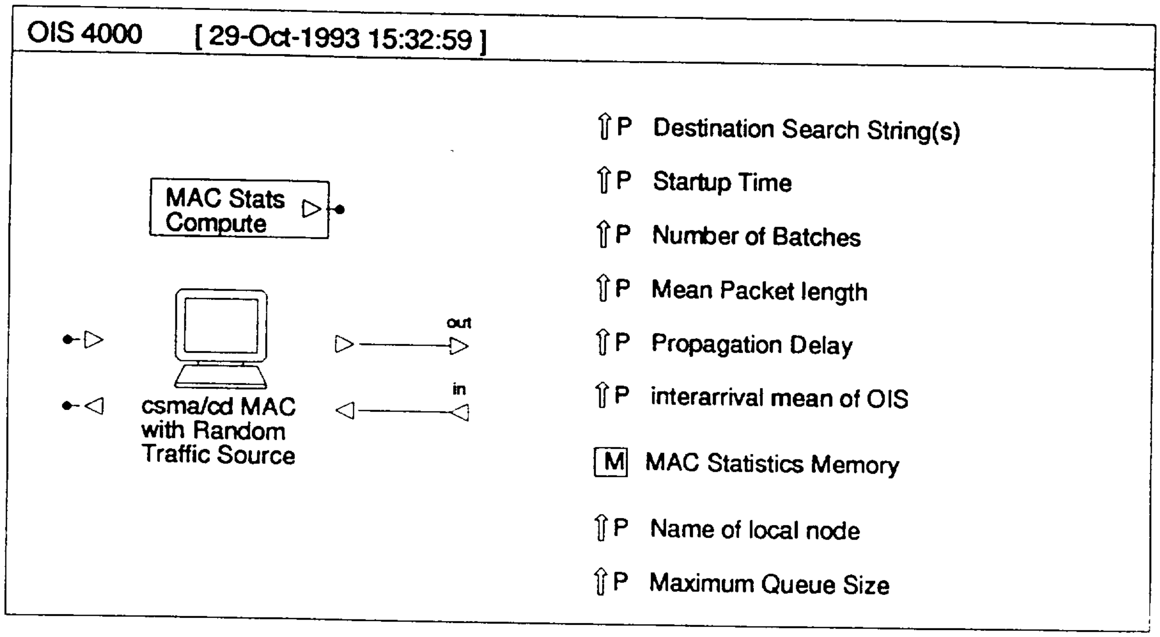


Figure A.23 OIS 4000 Model

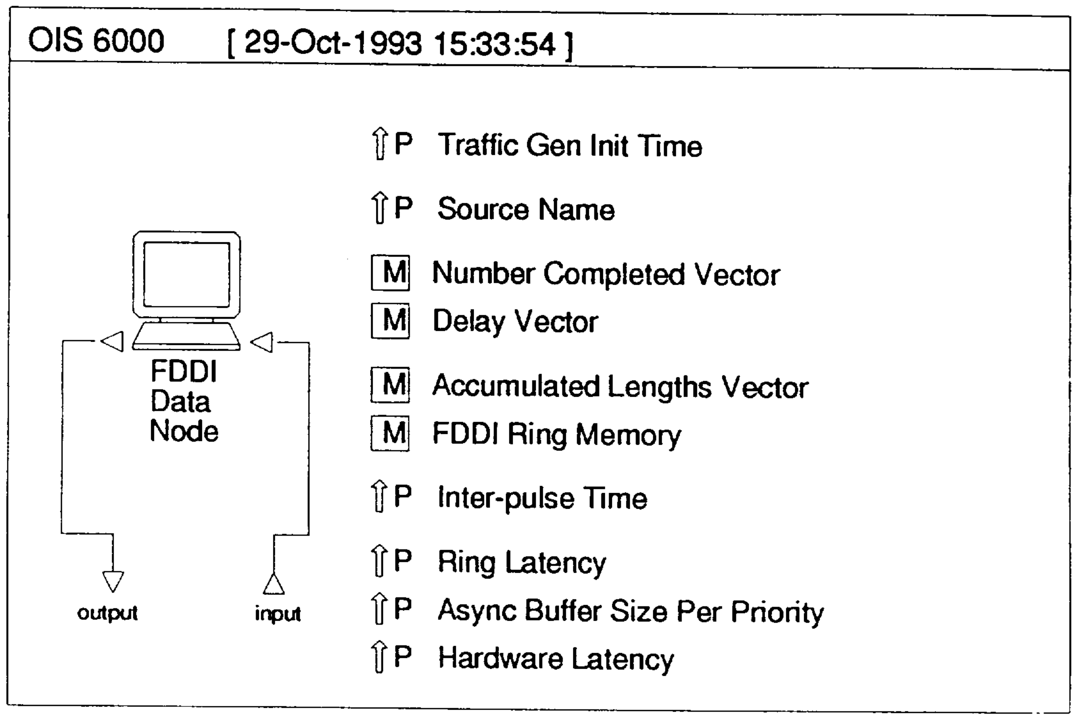


Figure A.24 OIS 6000 Model

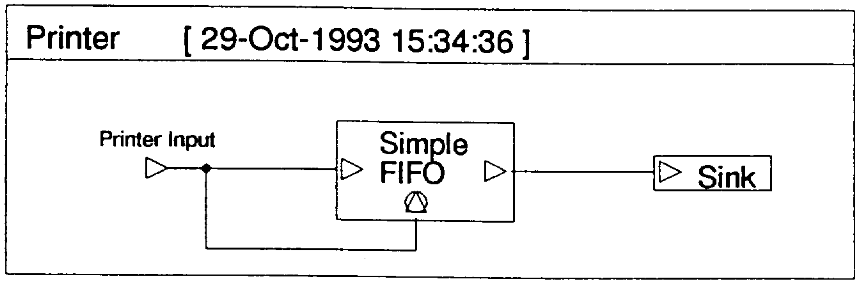


Figure A.25 Printer Model

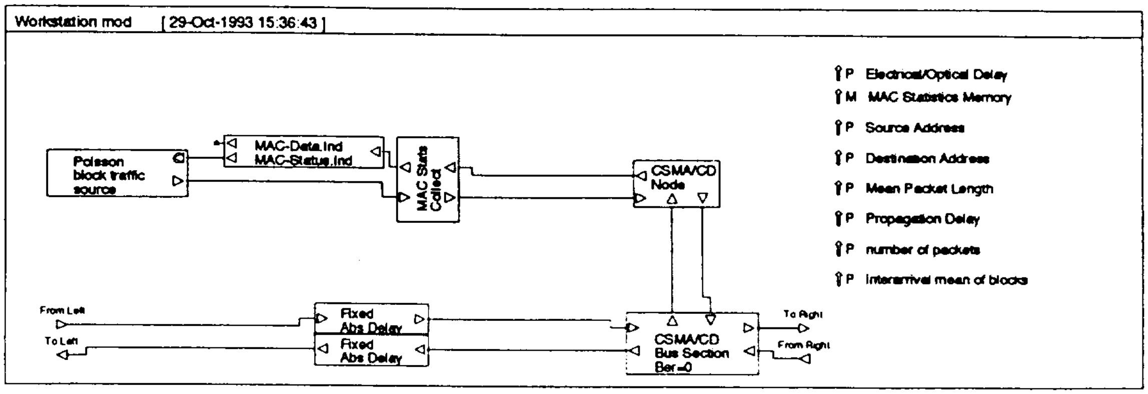


Figure A.26 Workstation Model

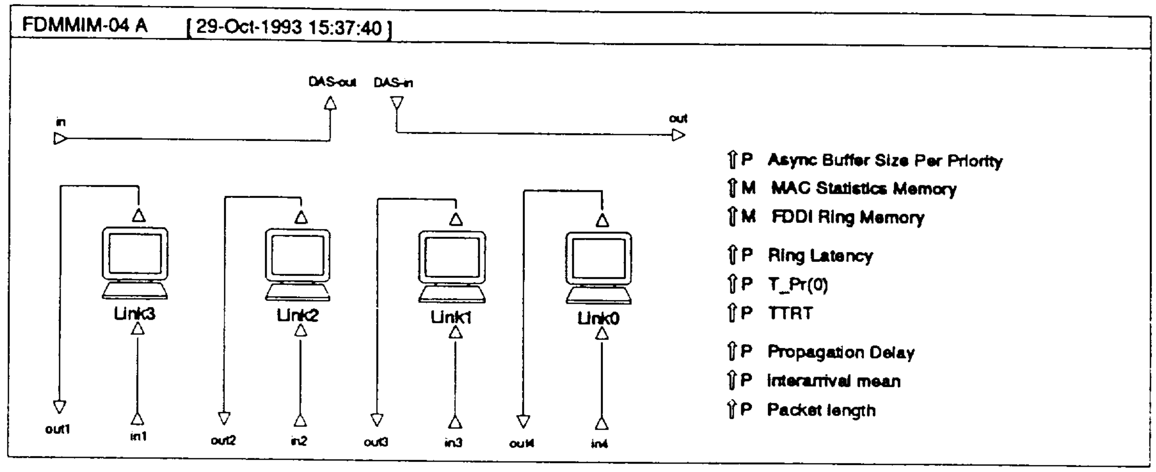


Figure A.27 FDMMIM–04 Model

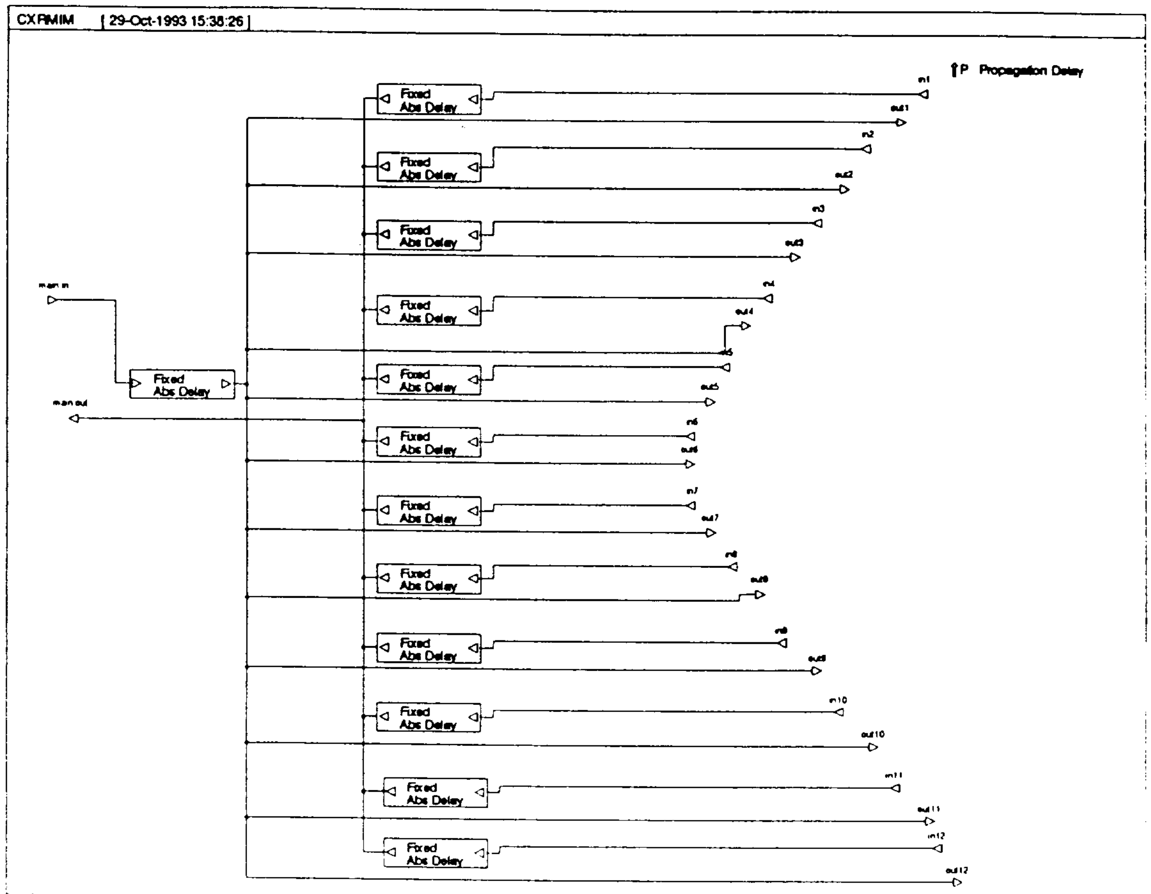


Figure A.28 CXRMIM Model

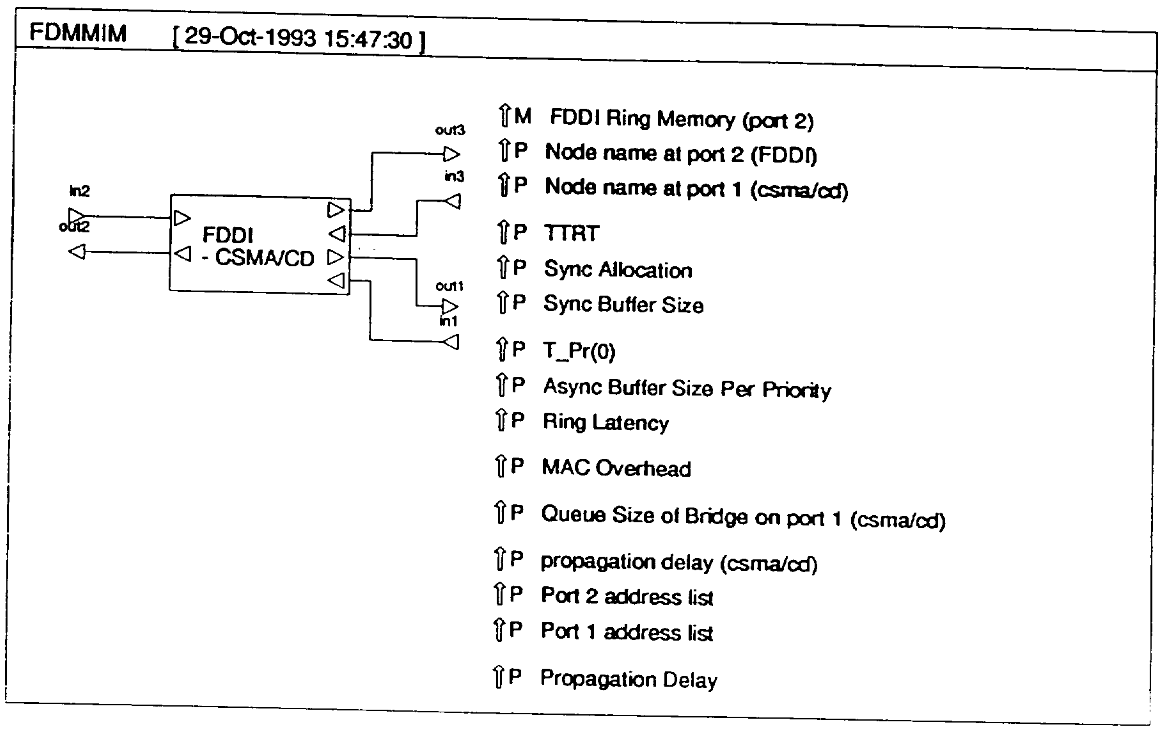


Figure A.29 FDMMIM Model

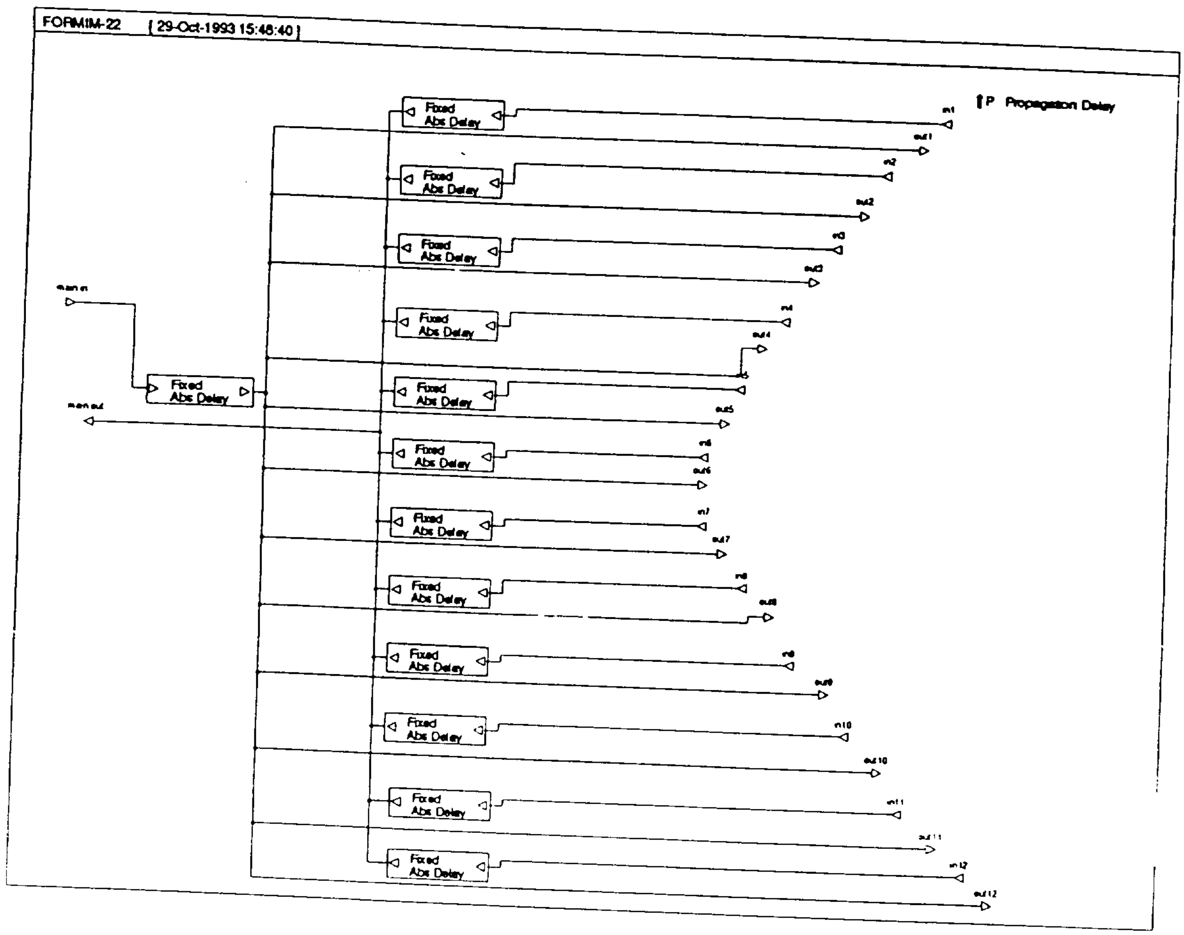


Figure A.30 FORMIM–22 Model

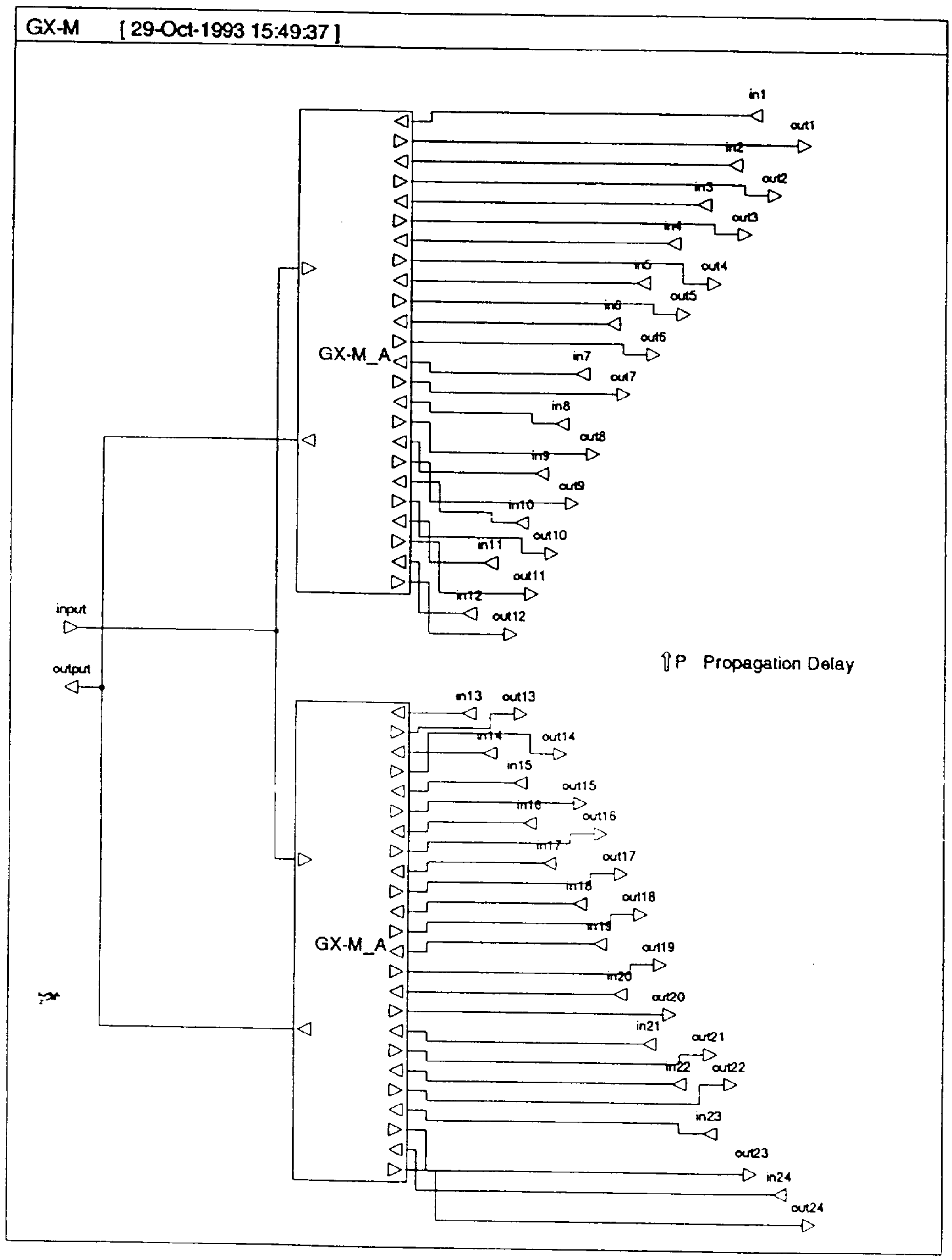


Figure A.31 GX–M Model

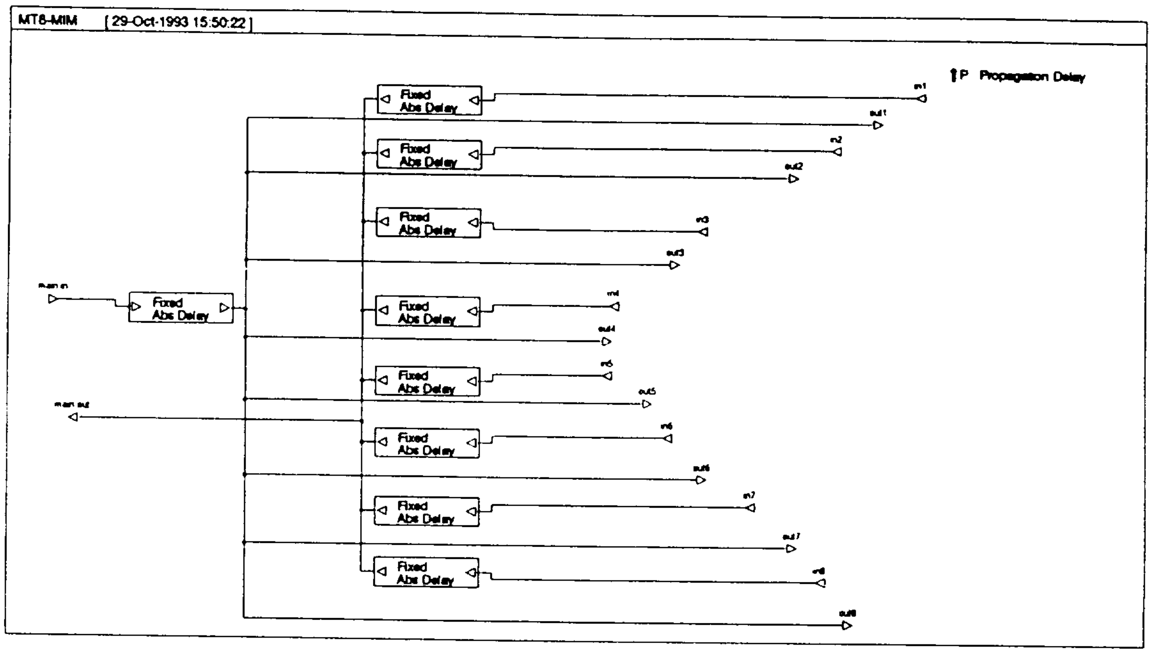


Figure A.32 MT8–MIM Model

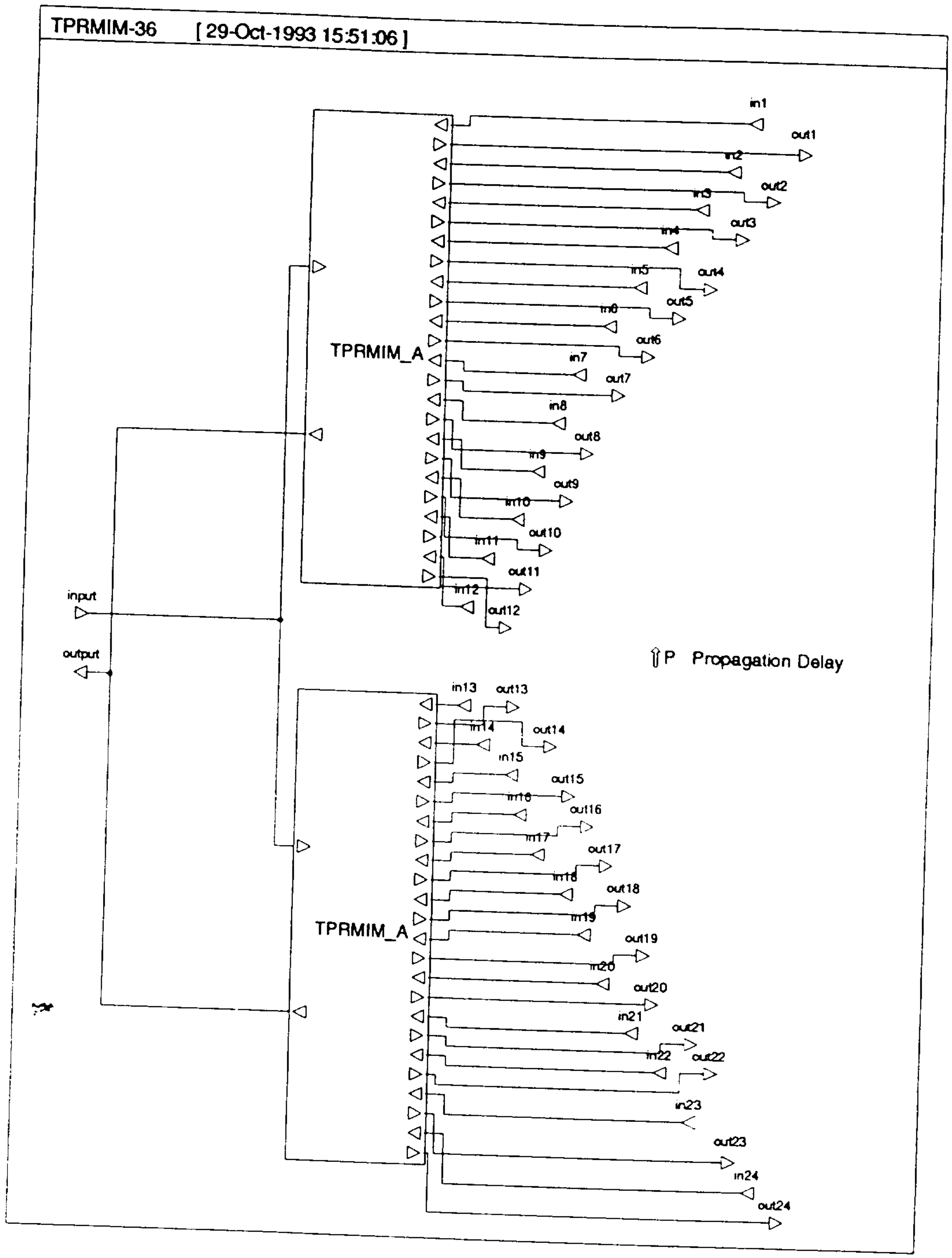


Figure A.33 TPRMIM–36 Model

# GLOSSARY

| | |
|---|---|
| ADI | Asynchronous Data Interface |
| API | Application Program Interface |
| ASC | Area Supervisory Computers |
| AUI | Access Unit Interface |
| BAS | Building Automation System |
| BIS | Business Information System |
| B_1000 | Building 1000 |
| BSGW | BASEstar Gateway |
| CAD | Computer Aided Design |
| DAS | Device Access Software |
| DCS | Device Control Software |
| DHI | Data Highway Interface |
| FALS | Fire And Line Safety |
| FDDI | Fiber Distributed Data Interface |
| FDLM | Fiber Distributed Line Module |
| FTP | File Transfer Protocol |
| LSC | Local Supervisory Computers |
| OIS | Operational Information System |
| NCT | Network Cooperating Task |
| NI | Network Interface |
| PAA | Process Automation Application |
| PAM | Process Automation Module |

| | |
|---|---|
| PE | Protocol Emulator |
| PSCNI | Program Support Communication Network–Internet |
| SR | Security Router |
| TCP/IP | Transmission Control Protocol/Internet Protocol |
| UPS | Uninterrupted Power Supply |
| UTP | Unshielded Twisted Pair |
| WS | Work–Stream |

# APPENDIX

## B. James' Project

# DEVELOPMENT OF AN OBJECT ORIENTED MODEL TO REPRESENT THE FUNCTIONALITY OF A CABLETRON HUB

By

James Franklin Dement

A Project
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Computer Science
in the Department of Computer Science

Mississippi State, Mississippi

November 1993

DEVELOPMENT OF AN OBJECT ORIENTED MODEL

TO REPRESENT THE FUNCTIONALITY OF A

CABLETRON HUB

By

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## ACKNOWLEDGEMENTS

Appreciation is expressed to Dr. Wayne Smith and Dr. Robert Moorhead for serving as project directors for this project. Their help and guidance throughout the project is greatly appreciated.

A special thanks is also expressed to Dr. Wayne Smith for serving as the author's major advisor. Dr. Smith has provided invaluable assistance to the author during his graduate career.

Appreciation is also expressed to Dr. Rainey Little for serving on the author's graduate committee. While covering pipelining in his Hardware course, Dr. Little also provided, indirectly, the solution to a major problem encountered during the researching of this project.

The author would also like to express his appreciation and thanks to Tom Ritter and Frank Peters. Without the information and knowledge gained from Tom and Frank, and especially without the assistance provided by Tom, this project and report would not have been completed. For patiently answering all the questions and participating in all of the endless discussions, thank you Tom and Frank.

The assistance provided by James Stevens and the technical staff at Cabletron is also appreciated. Through the many telephone conversations they were able to provide technical information that was vital to this project.

A special thanks also goes to NASA without whom this project would not have existed. NASA provided the funding and the subject for this research project.

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# CHAPTER I

# INTRODUCTION

This document is the project report for the directed project dealing with the software simulation of a Cabletron Hub. This project is for partial fulfillment of the requirements for the degree of Master of Computer Science in the Department of Computer Science at Mississippi State University. This report describes the goals and the results of the project, as well as the methods used to implement and test the final model.

## Project Objectives

The objectives of this project were two-fold. The first objective of this project was to design and build a model of the Cabletron Hub using the Block Oriented Network Simulator (BONeS) which was developed by Comdisco Systems, Inc. The second objective was to use this model in a network simulation to try to determine if the hub produced any bottlenecks that might be of importance to network designers, especially those involved in building the computer network at the Advanced Solid Rocket Motors (ASRM) plant in Iuka, Mississippi.

## Site Overview

The Advanced Solid Rocket Motor (ASRM) facility at Yellow Creek near Iuka, Mississippi is part of a National Aeronautics and Space Administration

(NASA) program to substantially improve the flight safety, reliability, productivity, and performance of the space shuttle's solid rocket motors. The ASRM is a replacement for the current space shuttle Redesigned Solid Rocket Motor (RSRM).

## Project Description

The computer network system at the ASRM plant uses Cabletron Multi Media Access Centers (MMACs) for its network interconnection. By researching the documents provided by Cabletron Systems, Inc. (Cabletron Systems Inc. 1989; 1992a-f), and by talking with the Cabletron technical personnel, it was possible to develop an understanding of how the Cabletron Media Interface Modules (MIMs) used at the ASRM facility interacted with each other. Using this information and the BONeS Block Diagram Editor, models were developed that would emulate the interaction and timing specification of the overall hub. By connecting the individual modules together, the completed hub could be used in network simulations designed to analyze the performance of the hub.

## Overview of the Report

In the following chapters, each of the individual Cabletron modules will be discussed in more detail, as well as the BONeS models that were used to implement the modules. Questions that were brought up over the course of the research, and the answers derived by the research will also be discussed. During the research, it was sometimes necessary to make assumptions either to simplify the construction of the models, or simply due to the fact that some information is proprietary and was unavailable to the researcher. The assumptions made, and the reasons for making the assumptions, are also discussed in the report.

# CHAPTER II

# CABLETRON DEVICES

The network structure of the entire ASRM complex consists of many separate networks (Moorhead et al 1993, 16). The networks make use of different types of transmission media as well as different communication protocols. Cabletron Multi Media Access Centers (MMACs), known as intelligent hubs, are used to interconnect the individual networks. The MMACs allow Ethernet, Token Ring, and FDDI networks to be connected together regardless of the transmission medium (Fiber, Twisted Pair, Coax, etc.) used (Cabletron Systems Inc. 1992e, 3). The following sections describe the individual components that were modeled, as well as giving some important characteristics of each.

## The MMAC Chassis

The MMAC chassis is a modular unit that is used to hold the individual modules that make up the complete MMAC. Cabletron manufactures three different models of the chassis; they are referred to as the MMAC-3FNB, 5FNB, and M8FNB, which contain slots for three, five, and eight media modules respectively. The MMAC-M8FNB, the only chassis used at the ASRM site, can provide up to 168 Ethernet ports (Cabletron Systems Inc. 1992e, 11). The first slot in each chassis must be populated with a Management / Repeater Module such as the EMME.

Built into the back of the chassis is the backplane. Cabletron has developed a flexible backplane known as the Flexible Network Bus (FNB). Modules inserted into the chassis connect to this bus, and are then able to transmit and receive data on this bus. The modules can be "hot swapped", which means the modules can be inserted and removed without powering down the entire MMAC.

The FNB consists of several smaller buses known as the Ethernet, Management, Power, Token Ring, and FDDI buses. The Ethernet bus is further broken down into the Ethernet A, B, and C buses. However, only the newer generation of multi-channel repeater modules such as the TPRMIM can access the B and C channels. Due to the flexibility of the FNB, the MMAC-FNB can be simultaneously populated with Ethernet, Token Ring, and FDDI modules.

## The EMME Module

The first slot in each MMAC must be populated with a Management / Repeater Module (Cabletron Systems Inc. 1992a, 3.3). The MMACs used at the ASRM site all contain the EMME, which is a new generation Ethernet Bridge and Management Module. The new generation modules are capable of accessing the internal B and C buses. The EMME bridges the internal Ethernet buses A, B, and C to the external Ethernet bus D. Ethernet bus D is the bus that connects to the front panel of the EMME.

The EMME is also capable of filtering traffic that passes through the bridge. The EMME stores the node addresses in an internal Source Address Table (SAT) capable of storing up to 8,191 Ethernet addresses (Cabletron Systems Inc. 1992e, 29). The EMME filters out packets whose destination does not reside on the opposite side of the bridge. This reduces the amount of traffic flowing across the bridge, thereby reducing the load on the entire network system. The database is "self-learning" and has a user configurable aging delay so that addresses that have not been active for a specified amount of time can be removed.

## The FORMIM Module

The Fiber Optic Repeater Media Interface Module (FORMIM) is a multi-channel 10BASE-FL repeater card (Cabletron Systems Inc. 1992e, 51). Multi-channel simply means that the module is capable of accessing the FNB (Ethernet channels B and C). The FORMIM-22 features 12 fiber optic ports mounted on the front panel.

Using the multiple internal Ethernet buses, this advanced Repeater Module can support two additional fully functional Ethernet networks within the same MMAC. The EMME described above is used to bridge these networks to the other existing Ethernet networks.

The FORMIM-22 utilizes the advanced Repeater Interface Controller (RIC) chip to provide full IEEE 802.3 compliant repeater capabilities to each port and each module on the MMACs internal Ethernet Channels. The RIC chip was co-developed by Cabletron and National Semiconductor (Cabletron Systems Inc. 1992d, 10).

All multi-channel repeater modules that utilize the RIC chip (RMIMs) can be configured by either software or hardware to operate in one of two modes. These modes are Ethernet B / C or Standalone. In the Ethernet B / C mode, the modules repeat packets independently between ports on the same module and ports on other modules connected to the same channel. In Standalone mode, the packets are not placed on the bus but rather are only repeated to other ports on the same module. Seven separately repeated Ethernet segments can be obtained using the MMAC-8FNB and seven RMIMs operating in Standalone mode.

## The CXRMIM Module

The Coaxial Repeater Media Interface Module (CXRMIM) is the same as the FORMIM described above except that the 12 fiber optic ports (10BASE-FL) are replaced by 12 thin wire coax ports (10BASE-2).

In addition to the 12 coax ports, the CXRMIM provides a user definable Ethernet Port Interface Module (EPIM) that permits the user to configure the module with a single port for a variety of media types. Network designers can choose from seven different types of EPIMs including an Access Unit Interface (AUI), twisted pair, fiber optic, and coax media. All EPIMs are "hot swappable" and can be inserted through the front panel of the CXRMIM.

## The TPRMIM Module

The Twisted Pair Repeater Media Interface Modules (TPRMIMs) are fault tolerant multi channel 10BASE-T modules. The TPRMIM-33 and TPRMIM-36 provide 13 and 26 10BASE-T connections respectively.

## The FDMMIM Module

The FDDI modules manufactured by Cabletron Systems provide high performance Ethernet to FDDI bridging, as well as FDDI concentrator capabilities. These features allow for designs that include Ethernet to the desktop and FDDI to the desktop from the same MMAC (Cabletron Systems Inc. 1992e, 51).

The FDDI Management Media Interface Module (FDMMIM) is the first single channel module discussed so far. Unlike the multi-channel Ethernet modules, single channel modules do not have the ability to access the FNB Ethernet B and C buses. The FDMMIM is a full performance Ethernet to FDDI bridge module. It provides the connections between a 10 Mega bit per second (Mbps) Ethernet network (regardless of the number of nodes or media type), and a 100 Mbps FDDI backbone.

The FDMMIM connects to the FDDI backbone via two MIC connectors on the front panel. In the event that one of the FDDI rings is severed or broken in some other manner, the FDMMIM will automatically "wrap" to the secondary ring to continue communication. The FDMMIM also provides for an optical bypass switch. This is an external passive device which will provide optical continuity in case of power failure or other node failure.

To communicate with the Ethernet network, the FDMMIM communicates with the Ethernet bus A on the MMAC backplane. Through this bus, the FDMMIM can communicate with every Ethernet module in the chassis. This limits the number of Ethernet connections through the same FDDI module only by the number of Ethernet connections installed in the MMAC.

The FDMMIM-04 has all of the features of the FDMMIM described above, but also contains four concentrator ports for FDDI connections. The four concentrator ports are provided by the additional four MIC connections located on the front panel. Using the concentrator ports, up to four Single Attached stations can be connected to the FDDI backbone.

The MT8-MIM Module

The MT8-MIM coaxial concentrator module provides eight male Ethernet / IEEE 802.3 Access Unit Interface (AUI) transceiver attachments. Each of these AUI attachments can be connected to the AUI port of any network device. The MT8-MIM is a manageable module which provides all the functionality of a multiport transceiver, yet integrates into the MMAC chassis.

Filtering and Forwarding Characteristics

Only two of the modules that have been discussed are capable of filtering and forwarding data packets, the EMME and the FDMMIM. The EMME is an Ethernet to Ethernet bridge and has the capability of bridging the four Ethernet channels (Buses A, B, C, and D) together at "wire speed." This allows for four independently repeated Ethernet segments. The EMME documentation states that the EMME filters packets at the rate of 28,000 packets per second (pps) and is capable of forwarding packets at up to 20,000 packets per second (Cabletron Systems Inc. 1992e, 29).

The FDMMIM module is an Ethernet to FDDI bridge. Packets that enter the Ethernet A channel are examined by the FDMMIM, and are forwarded to the FDDI network by the FDMMIM, if needed; otherwise they are just discarded. The FDMMIM likewise examines packets that enter the module on the FDDI network for possible forwarding to the Ethernet A channel. To transfer Ethernet to FDDI, or FDDI to Ethernet, the FDMMIM must first convert the packet from one protocol format to the other. The FDMMIM documentation states that the FDMMIM filters Ethernet packets at the rate of 14,880 pps, and filters FDDI packets at a rate of 446,429 pps. Packets are forwarded in either direction at the rate of 14,880 pps (Cabletron Systems Inc. 1992c, B.2).

# CHAPTER III

# TECHNICAL INFORMATION

In this chapter the technical details that were uncovered during the research phase are discussed. This information can be broken down into five distinct areas. The five areas include: hardware architecture, hardware port delays, repeater delays, bridge forwarding latency, and bridge buffering capacity.

## Hardware Architecture

The first approach the researcher used was to try to model the Cabletron Hub using the hub's actual hardware construction as the basis for the model. This included the modeling of the backplane of the hub and the protocols used to transfer data from one module to the other. This type of information proved to be unavailable due to proprietary concerns. Even if this information had been available, it is doubtful the researcher would have been able to develop an accurate model due to the immense complexity of the hardware.

Since the performance of the hub is based on delays and throughput, it was decided to approach the model from a performance point of view. By examining the reported figures for delays and throughput of the modules, it should be possible to build a model that produces the same performance statistics as those reported by Cabletron Systems, Inc.

By examining the Cabletron documents, and talking with Cabletron technical consultants, it was determined that delays were introduced by the hub at three key locations: port hardware delay, repeater delay, and bridge delay. Each of these locations is discussed in more detail in the following sections.

## Port Hardware Delays

There is a delay introduced in the data path at the point where the different physical media types are connected to the front panel. For example, there is a delay introduced by the Fiber Optic Repeater Media Interface Module (FORMIM) when it converts the incoming optical signal into an electronic signal. In the same manner, there is a delay when converting an electrical signal to an optical signal. Each module introduces a small delay in this fashion.

## Repeater Delays

Another source of delay is the time required for the repeater hardware to retime and retransmit packets. The standard delay for a Cabletron repeater is 1.55μs (Tom Bell, telephone interview, 16 September 1993). Data enters the MMAC via a port on the front panel of one of the MIMs. Before that data exits the MMAC, it must first pass through at least one repeater (Tom Bell, telephone interview, 16 September 1993). There are two exceptions to this rule, however. The first exception is a packet entering the MT8-MIM and exiting another port on that same MT8-MIM. Since the MT8-MIM is a transceiver module, data does not have to pass through a repeater. The standard delay introduced by the transceiver is .864μs. The other exception is when a packet enters one Ethernet bus, and exits another Ethernet bus. In this case the packet will pass through two repeaters (Tom Bell, telephone interview, 16 September 1993).

## Bridge Delays

The third source of major delay is the delay incurred by a packet when it passes through a bridge. A packet must pass through a bridge when it enters an Ethernet bus (Ethernet A, B, C, or D) and exits on a different bus. In addition to this Ethernet to Ethernet bridge, there is a FDDI to / from Ethernet Bridge in the FDMMIM module. Any packet passing between FDDI and Ethernet must first pass through this bridge. Packets that pass between Ethernet B or C buses and the FDDI module must pass through two bridges, the EMME and the FDMMIM (Tom Bell, telephone interview, 16 September 1993). The EMME installation guide reports that the latency of the Ethernet to Ethernet bridge is 91μs (Cabletron Systems Inc. 1992a, A.1). No latency was reported for the FDMMIM modules.

# CHAPTER IV

## BONeS IMPLEMENTATION

In the following sections, a brief overview of BONeS is given along with a discussion of the methods used to model the port delays and delays introduced by the bridges. In addition to the delays, it is necessary to model the buffering capacity of the bridges. The method used to model the buffering capacity is also discussed in the following sections. It should be noted that BONeS does not actually care what physical media type is used, it deals strictly with data structures and specified delays. Before the discussion of the implementation, the assumptions that were made will be given.

### BONeS Overview

The Block Oriented Network Simulator (BONeS) provides an interactive graphical environment for simulation-based analysis and design of a broad range of communication networks. BONeS includes an easy-to-use modeling and simulation environment, an excellent modeling library that is user extensible, and a set of powerful analysis tools. These features allow the user to concentrate on the modeling and analysis of the design rather than having to work with the low level details of simulation programming.

## Assumptions Made

The EMME is actually a self learning bridge. This simply means that when the bridge is first connected, it does not know all of the addresses for the nodes that are connected to it; it must first "learn" their addresses. When a packet enters the EMME and its destination address is unknown, the EMME forwards the packet to all channels. After the EMME learns the location of nodes from their source addresses, it will start to filter packets from the network segments that do not contain that node, and will forward the packet to the one network that does. The addresses are stored in a Source Address Table (SAT). The EMME is capable of storing up to 8,191 addresses in this SAT (Cabletron Systems Inc. 1992e, 29).

Since there are only about 200 nodes connected to the entire ASRM network, and since the "learning" process is significant only when a hub is first brought on line, the "learning" process and the SAT are not modeled. It is assumed that the hub already knows where the nodes on the network are located and that it will begin to forward packets to the proper locations immediately.

## Port Hardware Delays

In order to simulate the different delays introduced by the hardware port connections, absolute delays were placed at the entrance and exit of each port on a module. The delays for each type of connection are given in the list below (Cabletron Systems Inc. 1992c, 2.7).

1. Transceiver Port Delays : .864µs
2. Fiber Optic Connections : .900µs
3. Other Connections : .51µs

## EMME Bridge Processing Delay

According to the EMME installation guide, the EMME filters packets at 30,000 pps, and forwards at 18,000 pps (Cabletron Systems Inc. 1992a, A.1). This did not agree with the numbers reported in the Multi Media Access Center Products Catalog (Cabletron Systems Inc. 1992e, 29). In this document, the filtering rate is reported to be 28,000 pps and the forwarding rate is reported to be 20,000 pps. When questioned, Cabletron's technical personnel reported that the correct figures are 28,000 pps for filtering, and 18,000 pps for the forwarding capability, under ideal conditions with 64 byte packets. At first it was not obvious to the researcher how 18,000 pps could be obtained when the latency was reported to be only 91μs. At 91μs per packet, it seemed that the maximum number of pps would be 1/91μs, which is approximately 11,000.

When actually designing the model, however, the researcher discovered that by taking the delay introduced during the filtering stage, and adding the delay required in the forwarding stage to obtain 18,000 pps, the overall delay is very close to 91μs. This is shown by the equation:

(1) $$1/28{,}000 + 1/18{,}000 = 91.27\mu s$$

Using the assumption that the bridge processing must be pipelined, a bridge model was devised such that the filtering and forwarding phases were working in parallel as they would in a regular pipelined architecture. Figure 1 given below shows the completed EMME routing module.

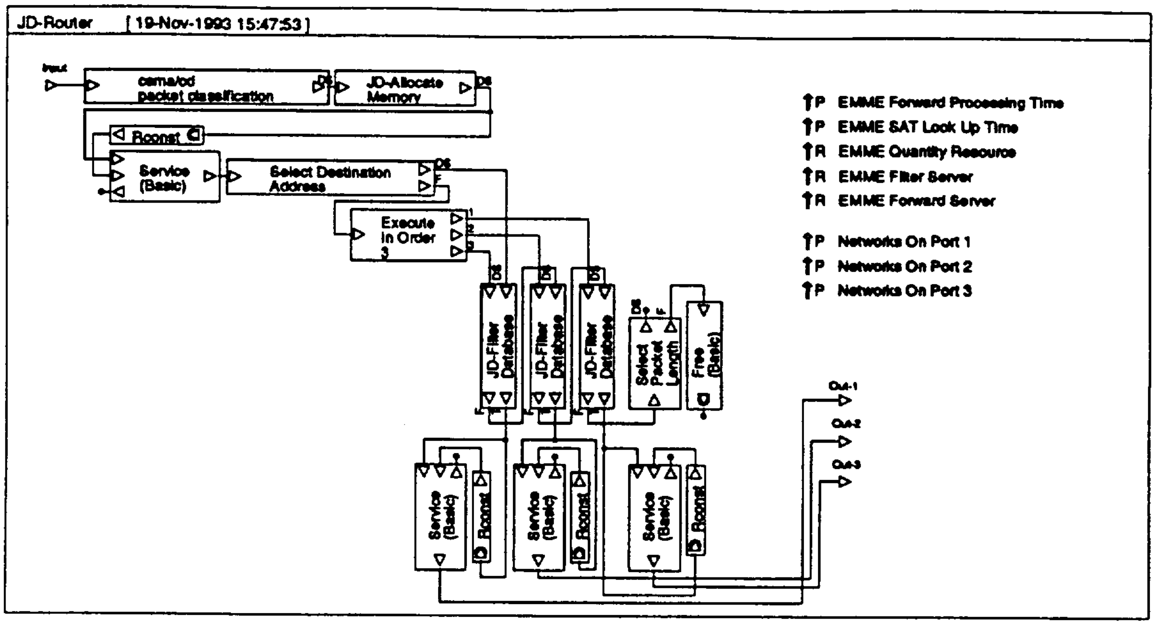


Figure 1. Block diagram of the EMME routing module

As was stated earlier, the EMME has the capability to bridge together four different Ethernet channels. To model this capability, nine bridges were required in the EMME alone. A method had to be devised that would allow the nine bridges to act as a single multi-port bridge. This was accomplished by using Server Resources which are provided by BONeS. In essence, the nine bridges compete for a single CPU resource to obtain their processing times. If data is only entering one channel, then only one bridge needs processing time, and it has the full power of the CPU to itself. If all channels are active however, they will share the CPU resource. The result is that all bridges put together will have a total throughput of only 18,000 pps for forwarding, and 28,000 pps for filtering.

## FDMMIM Bridge Processing Delay

The FDMMIM was modeled using the same pipeline principle that was used to model the EMME module. The FDDI filtering stage introduces a

1/446,429 second (2.24 μs) delay; the Ethernet filtering stage and the forwarding stage both introduce a 1/14,880 second (67.2 μs) delay. The completed FDMMIM bridge module is shown in Figure 2.

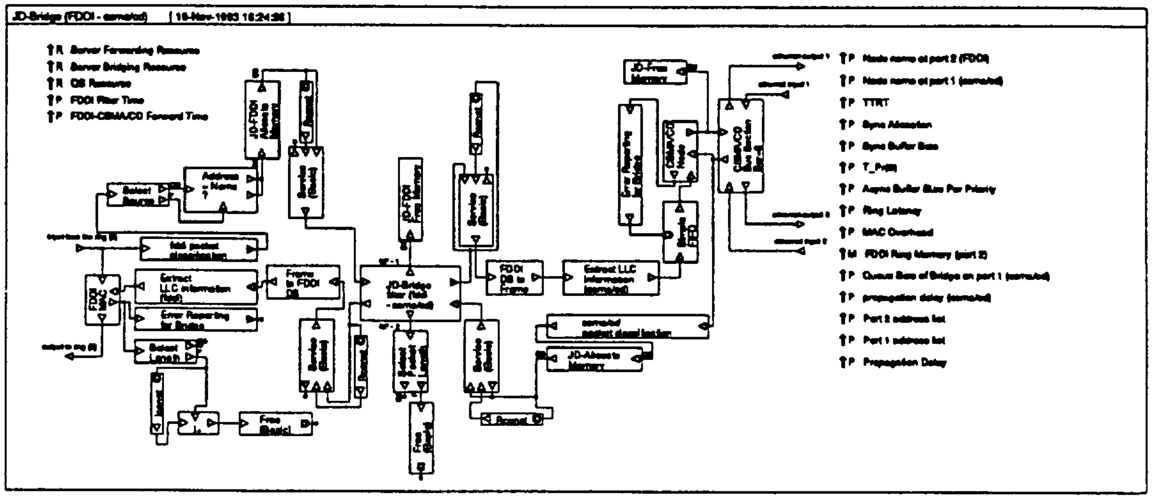

Figure 2. Block diagram of the FDDI to CSMA/CD bridge

Buffering Capacity of the EMME and FDMMIM

The buffering capacities of the EMME and the FDMMIM were modeled using quantity shared resources which are provided by BONeS. This resource is basically a pool of tokens. The tokens are removed by a module called "allocate" and are returned by a module called "free". For each module a pool was created containing four million tokens. The four million tokens represent the four million bytes of buffer memory provided by the EMME and the FDMMIM (Cabletron Systems Inc. 1992a, A.1; Cabletron Systems Inc. 1992c, 1.7).

When a packet first enters either the EMME or the FDMMIM, the module tries to allocate the number of tokens equal to the length of the packet in bytes. If there are not enough tokens available, then the buffer is full and the packet is discarded. If there are enough tokens, then they are removed from the pool, and the packet is put into the queue for processing. If the bridge filters out the packet, then the tokens are returned to the pool by the bridge for use by another packet. If the bridge forwards the packet to another channel, the tokens are returned to the pool as soon as the packet successfully exits the module.

## CHAPTER V

## CONNECTING MODULES

This chapter deals with the connecting of modules together to form the network hub. The manner in which the hubs are connected is important; invalid results are produced if they are connected incorrectly.

### Connecting to the EMME

The EMME module is required in any hub that is to provide management or bridging functions to the Ethernet channels. In addition to the management and bridging functions, the EMME provides the repeater for the modules on the Ethernet A channel.

The EMME module, shown below in Figure 3, has connections for four Ethernet segments. The connections are labeled A through D. Channels A through C represent the three Ethernet channels on the MMAC backplane. The fourth channel, channel D, represents the Ethernet connection on the front panel of the module. If the user does not intend to use all four channels, then the vacant channels must be "terminated" using the terminator provided by BONeS.

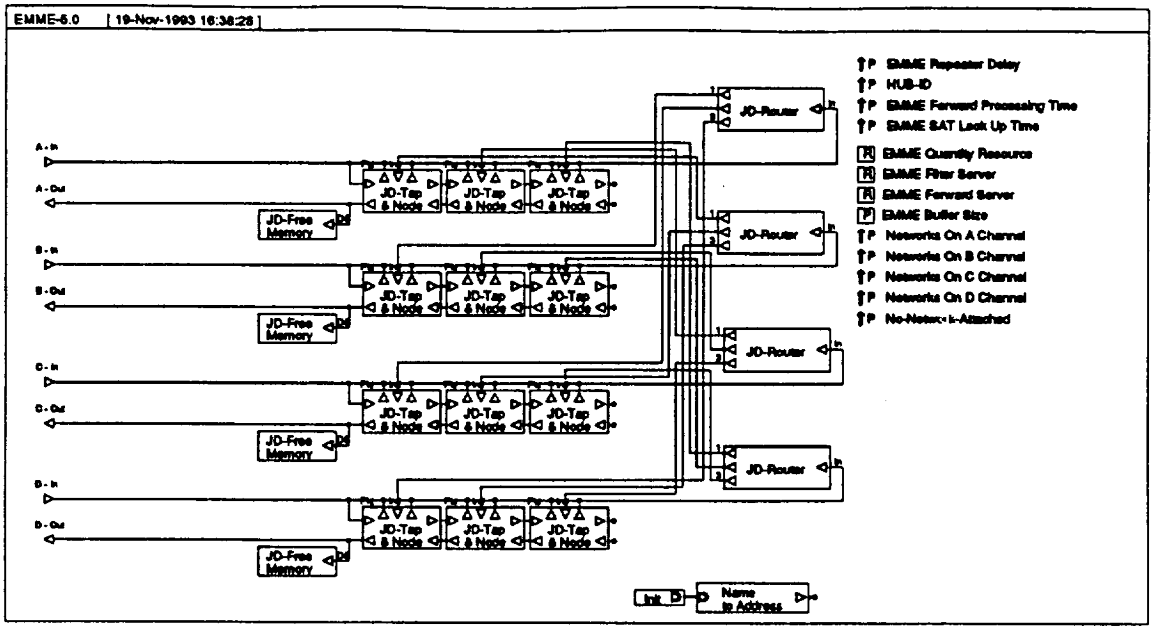


Figure 3. Block diagram of the complete EMME module

The A channel of the EMME should be connected to the first generation of Ethernet MIMs such as the MT8-MIM. Unlike the repeater modules, the first generation modules depend on the management card to provide the repeater function. The FDDI management modules, such as the FDMMIM or FDMMIM-04, can also be connected to this channel. This will provide the FDDI to Ethernet bridging capabilities.

When two or more modules are to be placed on the same Ethernet channel, the modules should be daisy chained together. On each module there is an Ethernet "In" channel and an Ethernet "Out" channel. The "Out" channel of one module is to be connected to the "In" channel of the next module. The last module in the chain must have its "Out" channel terminated using the terminator provided by BONeS.

The repeater modules such as the TPRMIM and CXRMIM can only be connected to Ethernet channels B and C. These modules have a built-in repeater and do not require the EMME to provide the repeater functionality.

## Connecting to the FDMMIM

The FDMMIM module, shown below in Figure 4, has three basic ports. The first port is an Ethernet "In" port and is to be connected to the Ethernet A channel. The second port is an Ethernet "Out" port and should be connected to the next FDMMIM or FDMMIM-04 module or terminated if the FDMMIM is the last module in the chain. The third port is the connection point for the FDDI ring. In addition to this FDDI ring connection, the FDMMIM-04 provides four concentrator port connections.

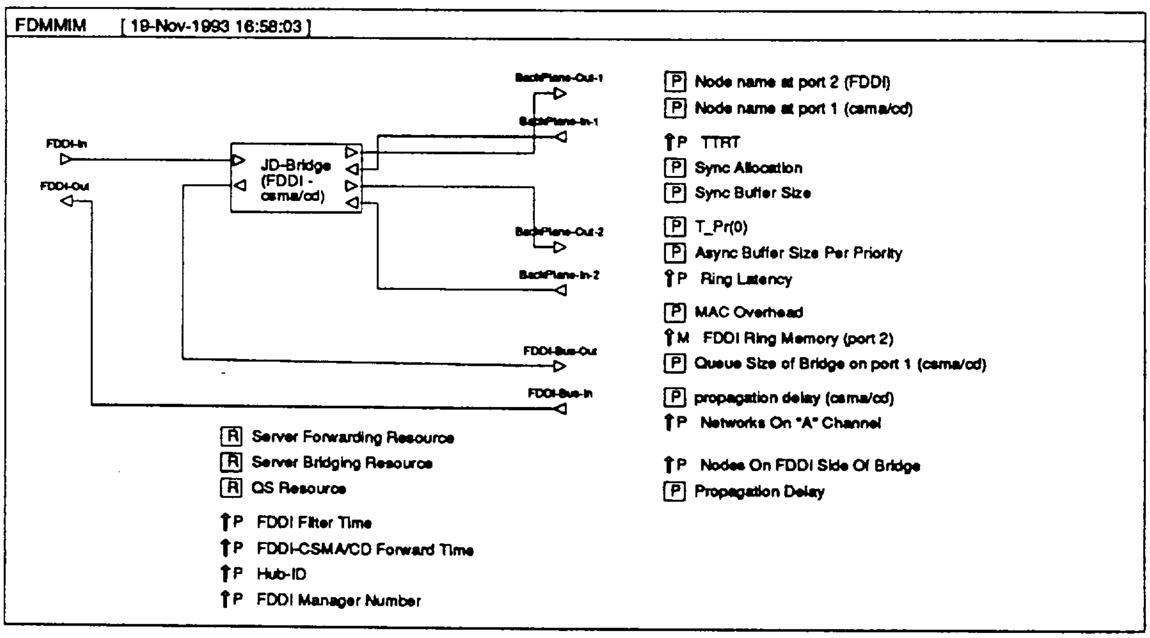


Figure 4. Block diagram of the complete FDMMIM module

## Media Interface Modules

The Media Interface Modules (MIMs) all have two Ethernet connections on the back to connect to the "backplane" of the MMAC. Two connections are provided in order to daisy chain modules together. Each MIM also includes Ethernet connections for the ports located on the front panel of the module. The MT8MIM, an example of a media interface module, is shown in Figure 5 below.

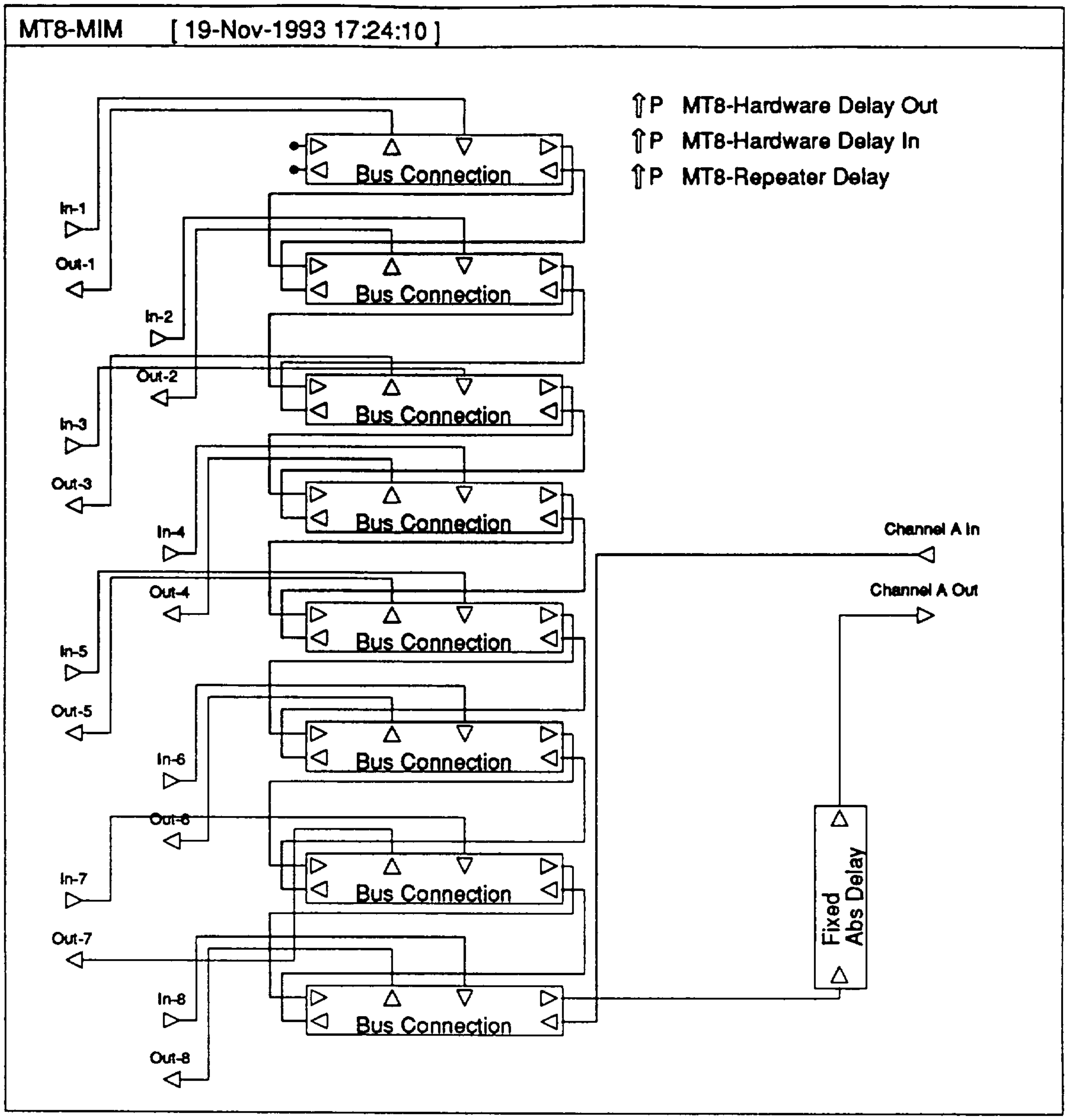


Figure 5. Block diagram of the MT8MIM module

# CHAPTER VI

# VERIFICATION AND VALIDATION

The main objective of the testing phase is to verify that the software models developed in the previous chapter produce the same results as the actual hardware devices. Before the actual experiments are described, it is first necessary to describe what the theoretical results of the models should be. Once the theoretical results are explained, the simulations used to test the models are described. Finally, the results of the test simulations are examined.

## Testing Background

The two metrics used to determine performance of the hub are throughput and delay. Cabletron provides the throughput and delay measurements for the EMME and FDMMIM modules. As we will see shortly, the EMME and FDMMIM modules are the only modules that need to have these measurements specified. All numbers given by Cabletron assume optimum operating conditions for the EMME and FDMMIM modules (Maurice Shagnon, telephone conversation, 18 October 1993). Optimum conditions include the modules' not being required to perform management functions and the data packets' being at the minimum legal length of 64 bytes (Maurice Shagnon, telephone conversation, 18 October 1993).

Why are the EMME and FDMMIM modules the only modules that have the throughput and delays specified? The EMME and the FDMMIM are bridging modules and are the only two modules that play an active role in the varying of these two measurements. The TPRMIM, CXRMIM, MT8-MIM, and the other MIMs introduce fixed delays according to the type of hardware port they utilize. For these modules, the delay is constant. The EMME and FDMMIM modules, however, vary in throughput and delay according to the loads that are placed on them. This variance is due to the processing and buffering of the bridges within these modules.

As was stated earlier, the non-bridge modules introduce a fixed delay in the path of the packet. Although this added delay is undesirable in the network, it works to the bridges' advantage. When the full network is in operation, delays increase the possibility of packets colliding with each other. Collisions reduce the throughput of the network. To prove this, two simple tests were conducted.

The first test involved a network with only two nodes. The first node transmitted data to the second node, and the second node collected statistics on the received throughput. Since there is only one source of traffic, there are no collisions on the network.

The second test involved a network consisting of three nodes, two nodes transmitting data to the third node. Once again, the third node collected statistics on the received throughput. Since there are two sources of traffic, collisions are possible.

The plots shown in Figures 6 and 7 display the results of the two tests in a graphical format. As can be seen from Figure 6, the maximum throughput obtained by the two node network is 5.476 million bits per second (Mbps). From Figure 7, it can be seen that collisions have reduced the maximum bandwidth to 5.445 Mbps.

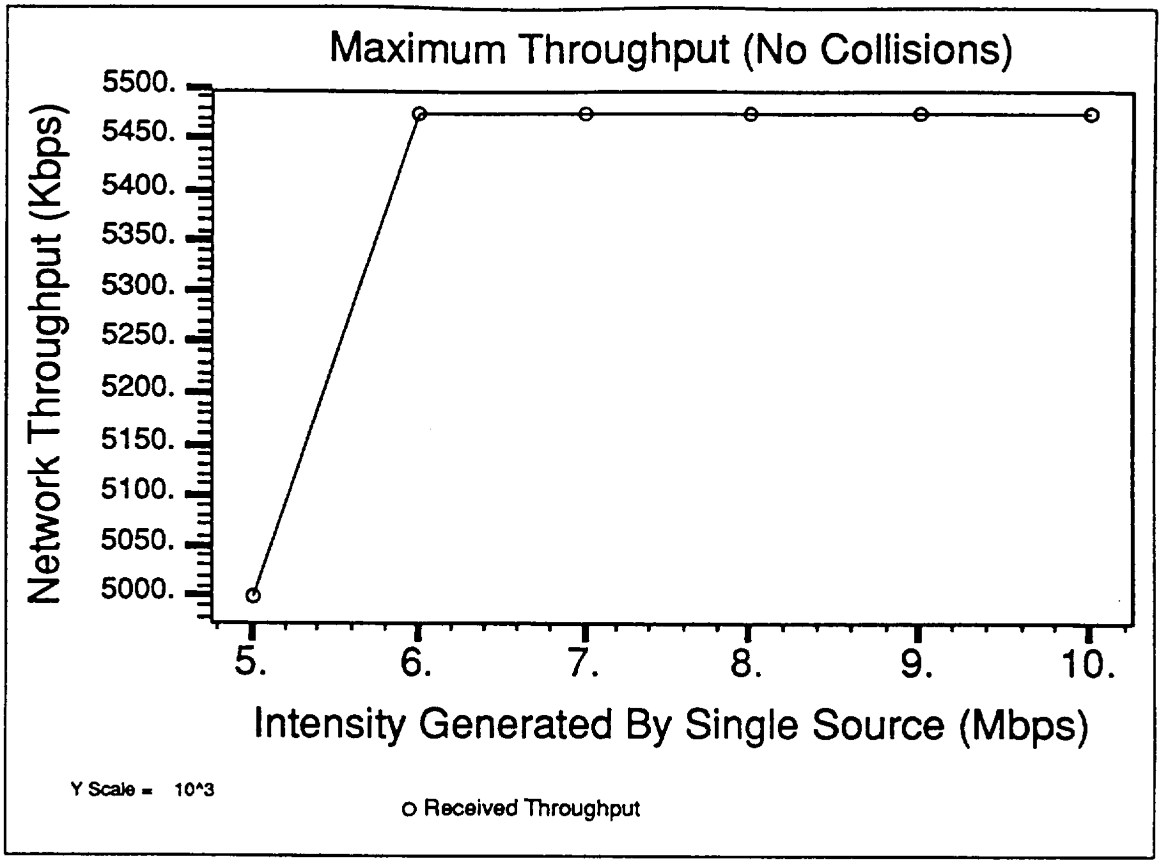


Figure 6. Plot showing maximum throughput achieved using one source

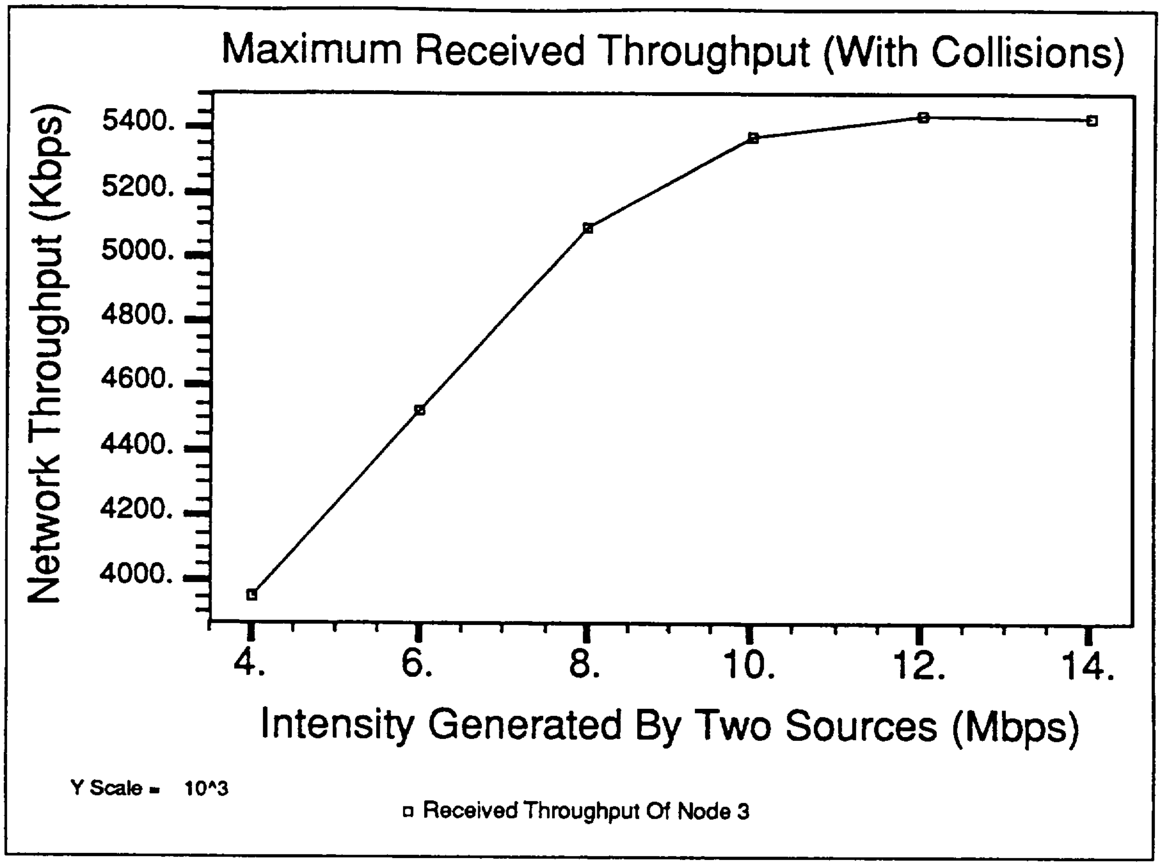


Figure 7. Plot showing maximum throughput achieved using two sources

A reduced throughput allows the bridge module to empty its buffer if the buffer has started to accumulate packets. Since collisions reduce the network's throughput, it is more important to verify that the EMME and FDMMIM modules are producing the expected results when no collisions are present. Once the bridge modules are verified, the other MIMs can be added to the hub to examine the overall performance of the entire hub when collisions are present.

## Protocol Maximum Throughput

In order to understand the results obtained during the testing phase, it is necessary to understand the communication protocols used by the MMAC. The two protocols that have been modeled include Ethernet and FDDI. The Ethernet frame format is shown below in Figure 8.

| Preamble | Destination Address | Source Address | Frame Type | Frame Data | CRC |
|---|---|---|---|---|---|
| 64 bits | 48 bits | 48 bits | 16 bits | – 368-12000 bits | 32 bits |

Figure 8. Format of the Ethernet frame

In addition to the frame size, the Ethernet protocol requires that a source keep a 96 bit gap between successive frames. This prevents one source from monopolizing the media. The total transmitted frame length is therefore 672 (512 frame bits + 64 bit preamble + 96 bit interframe gap) bits long. When considering the interframe gap, the maximum available throughput is calculated as follows:

(2) $$10 \text{ Mbps} * (576/672) = 8.571 \text{ Mbps}$$

As can be seen from the frame format in Figure 8, the minimum data size is 368 bits, which is the value used in a 64 byte packet. This observation is important because the BONeS probes used to measure throughput include only the user data. Therefore, the maximum bandwidth available for user data by a single user on a 10 Mbps Ethernet network, using a 64 byte packet, is

(3) $$10 \text{ Mbps} * (368/672) = 5.476 \text{ Mbps}.$$

Note that this is the maximum throughput obtained by the single source network as can be seen by Figure 6.

Fiber Distributed Data Interface (FDDI) has a total throughput of 100 Mbps. The FDDI frame format is shown below in Figure 9.

| Preamble | SD | FC | DA | SA | Info | FCS | ED | FS |
|---|---|---|---|---|---|---|---|---|
| 64 bits | 8 bits | 8 bits | 48 bits | 48 bits | 0+ bits | 32 bits | 4 bits | 12 bits |

SD = starting delimeter.
FC = frame control.
DA = destination address.
SA = source address.
FCS = frame-check sequence.
ED = ending delimeter.
FS = frame status

Figure 9. Format of the FDDI frame

The size of the data field was made to be 368 bits to remain consistent with the Ethernet data size used in testing. Given 224 bits of overhead, and 368 bits of data, FDDI has a maximum user throughput of

(4) $$100 \text{ Mbps} * (368/592) = 62.16 \text{ Mbps}.$$

Since FDDI is a token passing protocol, a minimum interframe gap is not required between FDDI frames. There is a gap associated with the rotational latency of the FDDI ring. This latency reduces the throughput available to a single source, but only by a negligible amount. The rotational latency is therefore not included in the calculations.

## EMME Theoretical Results

When verifying the operation of the EMME model, it was necessary to verify that the model exhibited the same filtering and forwarding characteristics as the real EMME. To accomplish this, the two characteristics were tested in two independent simulations. The two simulations are described in the following paragraphs.

The first simulation was used to verify that the EMME model produced the same filtering statistics as the real EMME. As was stated earlier, the EMME is capable of filtering packets at up to 28,000 pps when the packets are 64 bytes long. In order to generate the 28,000 pps, the input bandwidth to the EMME must be 14.336 Mbps (28k pps * 64 bytes per packet * 8 bits per byte). This value is greater than the 8.57 Mbps allowed by a single Ethernet channel with a single source. It was therefore necessary to use two Ethernet channels to input 14.336 Mbps into the EMME. When using BONeS to record throughput, only user throughput is recorded. Since there are 368 bits of user data in a 64 byte packet (512 bits), the user throughput will be

(5) $$14.336 \text{ Mbps} * 368/512 = 10.3 \text{ Mbps}.$$

What we expect to see is that the buffer in the EMME will begin to fill up at a much greater rate once the traffic entering the EMME exceeds 10.3 Mbps. The system that was used to test the filtering and bridging characteristics is shown below in Figure 10.

C-3.

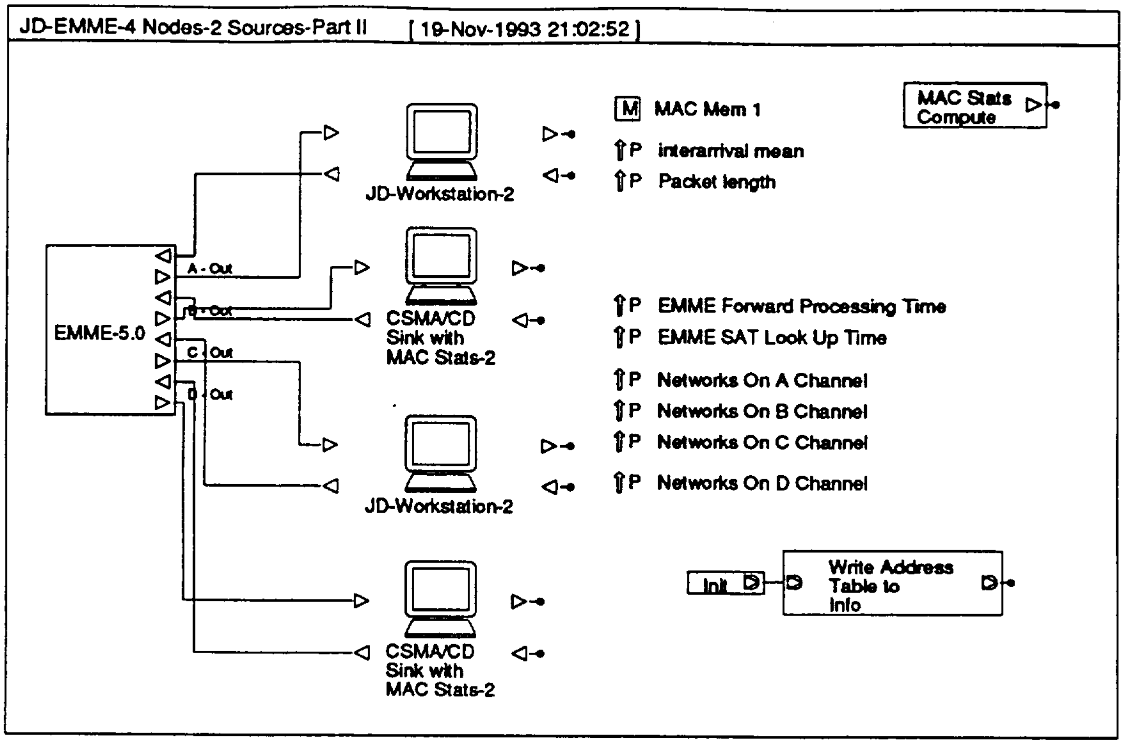


Figure 10. Block diagram of the system used to test the EMME module

The packets generated by the two workstations were addressed to stations that did not exist on any of the connected channels. Therefore, the packets entered the EMME, were processed, and were then discarded.

The second phase of testing the EMME module dealt with the forwarding capability. As was stated earlier, the EMME can forward packets at rates up to 18,000 pps. In order to generate 18,000 packets per second at 64 bytes a packet, it is necessary to generate data at 9.216 Mbps (18k pps * 64 bytes per packet * 8 bits per byte). Remember that BONeS only reports user throughput which will be

(6) $$9.216 \text{ Mbps} * 368/512 = 6.624 \text{ Mbps}.$$

Since the maximum throughput available to a single node on an Ethernet network is 8.57 Mbps, it was necessary once again to use two of the four Ethernet channels to input data into the EMME. The other two Ethernet channels were used to remove the data from the EMME once it had been processed. The same system model that was used to test the filtering characteristics was used to test the forwarding characteristics. (See Figure 10.)

## Results of the EMME Tests

The plots shown below in Figures 11 and 12 display the results of the simulations described above. According to Figure 11, the EMME model is capable of filtering packets up to 10.3 Mbps. The fact that the percentage used of the EMME buffer remains constant until just after the 10.3 Mbps mark proves this. Once the intensity is increased past the 10.3 Mbps mark however, the percentage of the EMME buffer that is used begins to increase. This shows that the EMME model is capable of handling traffic up to the 28,000 pps that is specified.

From Figure 12 it can be seen that the model successfully forwards packets as fast as they enter the EMME up until the traffic intensity reaches 6.62 Mbps. Once the user traffic intensity has reached 6.62 Mbps, 18000 pps are entering the EMME. When the intensity increases to a point above 6.62 Mbps, packets must be buffered and processed at a later time. The plot in Figure 12 shows that the model can only forward packets up to 18000 pps.

The plots displaying the results of the filtering and forwarding simulations indicate that the EMME model is indeed functioning as specified. The next module to be verified is the FDMMIM module.

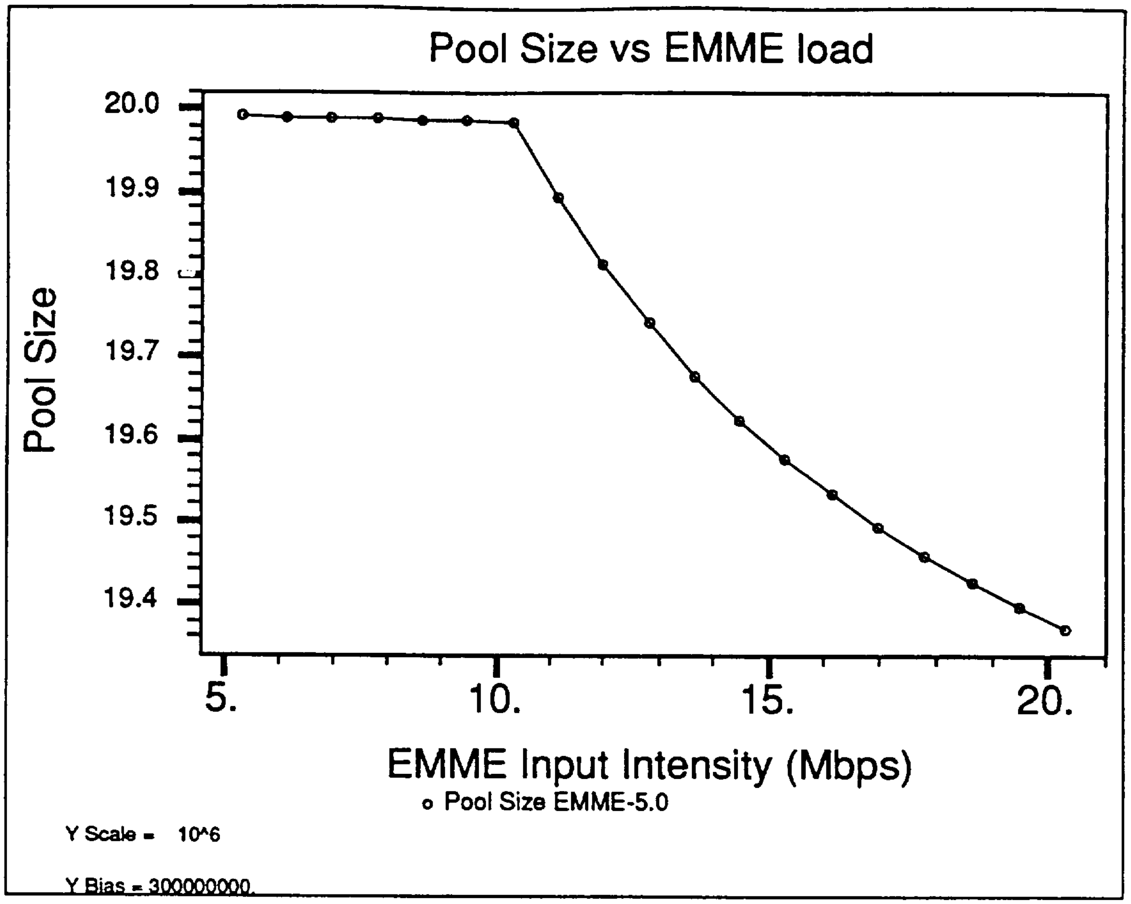


Figure 11. EMME buffer pool size versus the input load

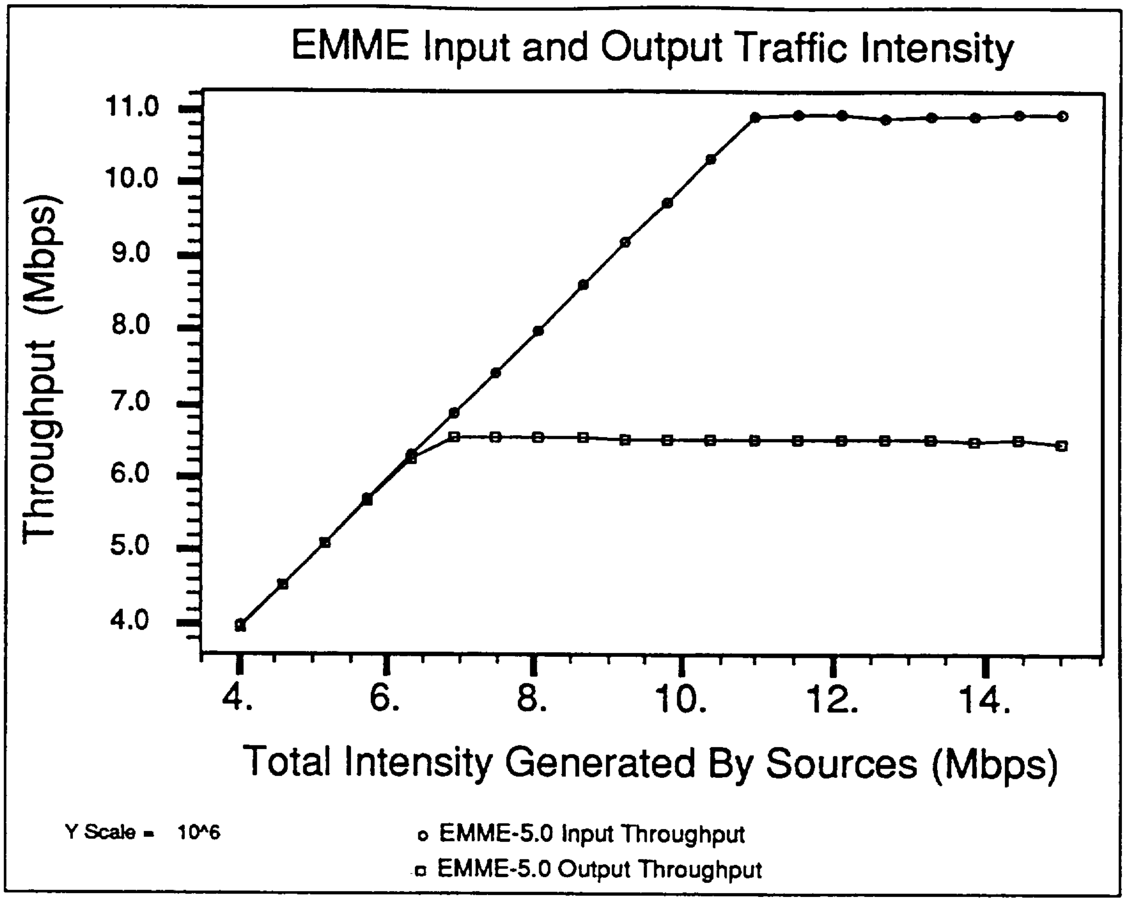


Figure 12. Forwarding input and output traffic intensity of the EMME

## FDMMIM Theoretical Results

As with the EMME model, it was necessary to verify that the FDMMIM model was operating correctly. The simulations were designed to test the throughput of the FDMMIM model. The FDMMIM module has a listed throughput of 446,429 pps when filtering FDDI packets, and a throughput of 14,880 pps when filtering Ethernet packets. It was noticed that in order for the FDMMIM to filter 446,429 pps the frame could be at most 224 bits. The following calculation illustrates this fact:

(7) $$100 \text{ Mbps} * (1 \text{ s} / 446{,}429 \text{ packets}) = 223.9 \text{ bits per packet}$$

As can be seen from the FDDI frame format shown in Figure 9, in order for the FDDI frame to be 224 bits, the data field must be zero bits wide. This means the FDMMIM is capable of filtering packets as fast as the FDDI protocol can send the packets. The same calculation can be made for filtering of Ethernet packets as well as the forwarding of Ethernet packets to and from the FDDI network:

(8) 10 Mbps * (1 s / 14,880 packets) = 672 bits per packet

The 672 bits per packet can be understood if we remember that there are 576 bits in a 64 byte packet with a 64 bit preamble, and that there is a 96 bit gap between pairs of packets from a single source. By adding the 576 bit frame and the 96 bit interframe gap, we get 672 bits. Once again, the FDMMIM is capable of filtering and forwarding packets as fast as the Ethernet protocol can deliver them.

When filtering packets, the FDMMIM is capable of filtering up to 446,429 pps for FDDI packets. Remember that the rate of 446,429 pps occurs at maximum throughput of the FDDI network. Testing should reveal that the buffer utilization of the FDMMIM levels off when maximum throughput is reached. If the buffer were to continue to fill up, then the processor would not be processing the packets fast enough. It was shown earlier in this chapter that given a 368 bit data field, the maximum user throughput available with FDDI should be 62.16 Mbps. Therefore, a plot of the buffer utilization versus the generated traffic intensity should level off around 62.16 Mbps.

To test the forwarding capabilities of the FDMMIM model, a plot showing the throughput of data as it enters and exits the FDMMIM is taken. Since the FDMMIM is capable of forwarding all types of packets at 14,880 pps, the plot should reveal that the maximum throughput exiting the FDMMIM is about 5.47 Mbps. This is the maximum user throughput available to a single Ethernet source, and the throughput needed to transmit 14,880 sixty-four byte packets in one second.

Figure 13 shows the system that was used to test the filtering and forwarding capabilities of the FDMMIM model. The results of the simulations are discussed in the next section.

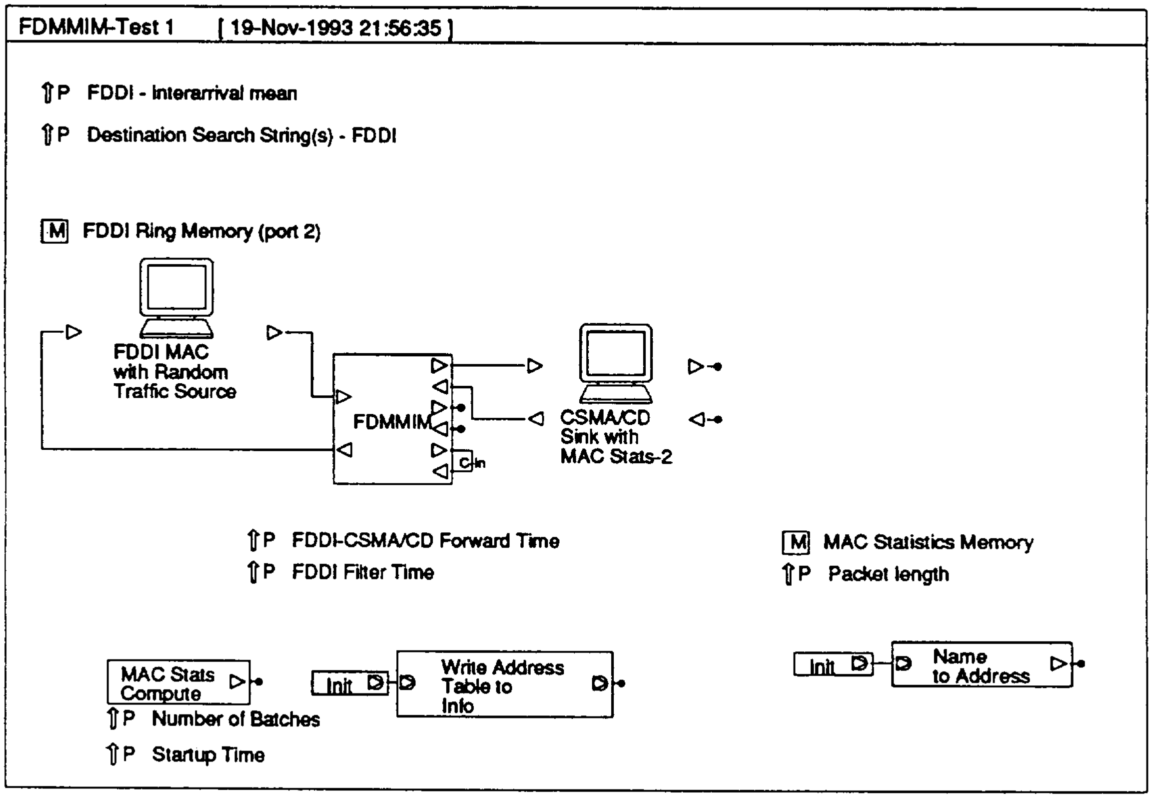


Figure 13. Block diagram of the system used to test the FDMMIM module

## The Results of the FDMMIM Tests

The result of the filtering test is given below in Figure 14. As can be from the plot, the buffer ceases to fill up once the incoming intensity reaches approximately 62.16 Mbps. As was explained earlier, 62.16 Mbps throughput is the maximum user throughput available, and since the buffer is no longer continuing to fill up, the FDMMIM model is indeed processing packets at the rate specified, 446,429 pps.

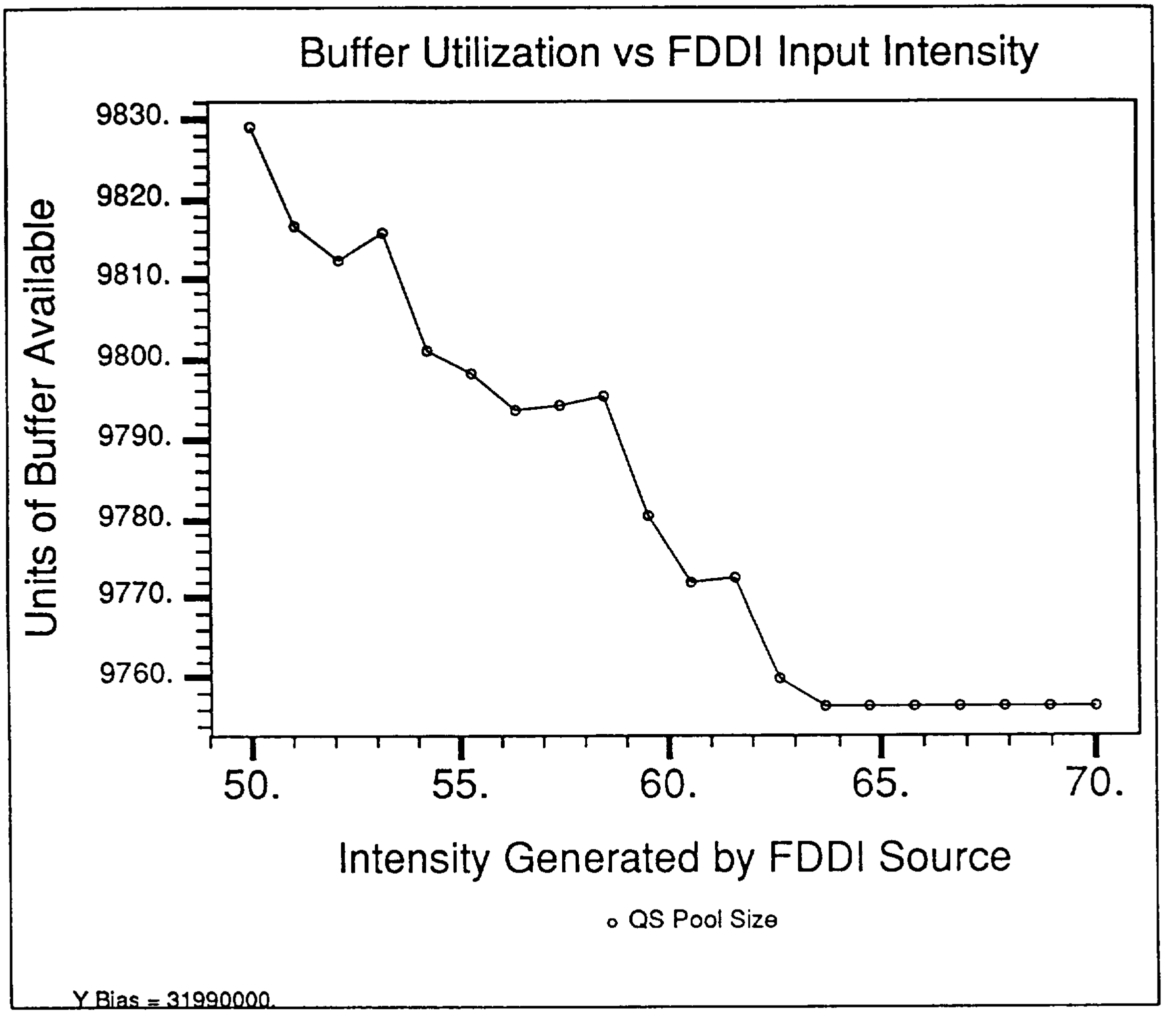


Figure 14. Plot showing result of the FDMMIM filtering test

The result of the forwarding test is given below in Figure 15. As can be seen from the plot, the traffic leaving the FDMMIM on the CSMA/CD network is equal to the traffic entering the FDMMIM from the FDDI network. At 5.48 Mbps, the FDMMIM is processing 14,880 pps. When the FDDI intensity passes the 5.48 Mbps mark, the FDMMIM must buffer the extra data. The plot shown in Figure 16 shows the FDMMIM buffer beginning to fill up at a much greater rate once the FDDI traffic intensity passes the 5.48 Mbps mark. The plots shown in Figures 15 and 16 show that the FDMMIM model is performing according to the given specifications.

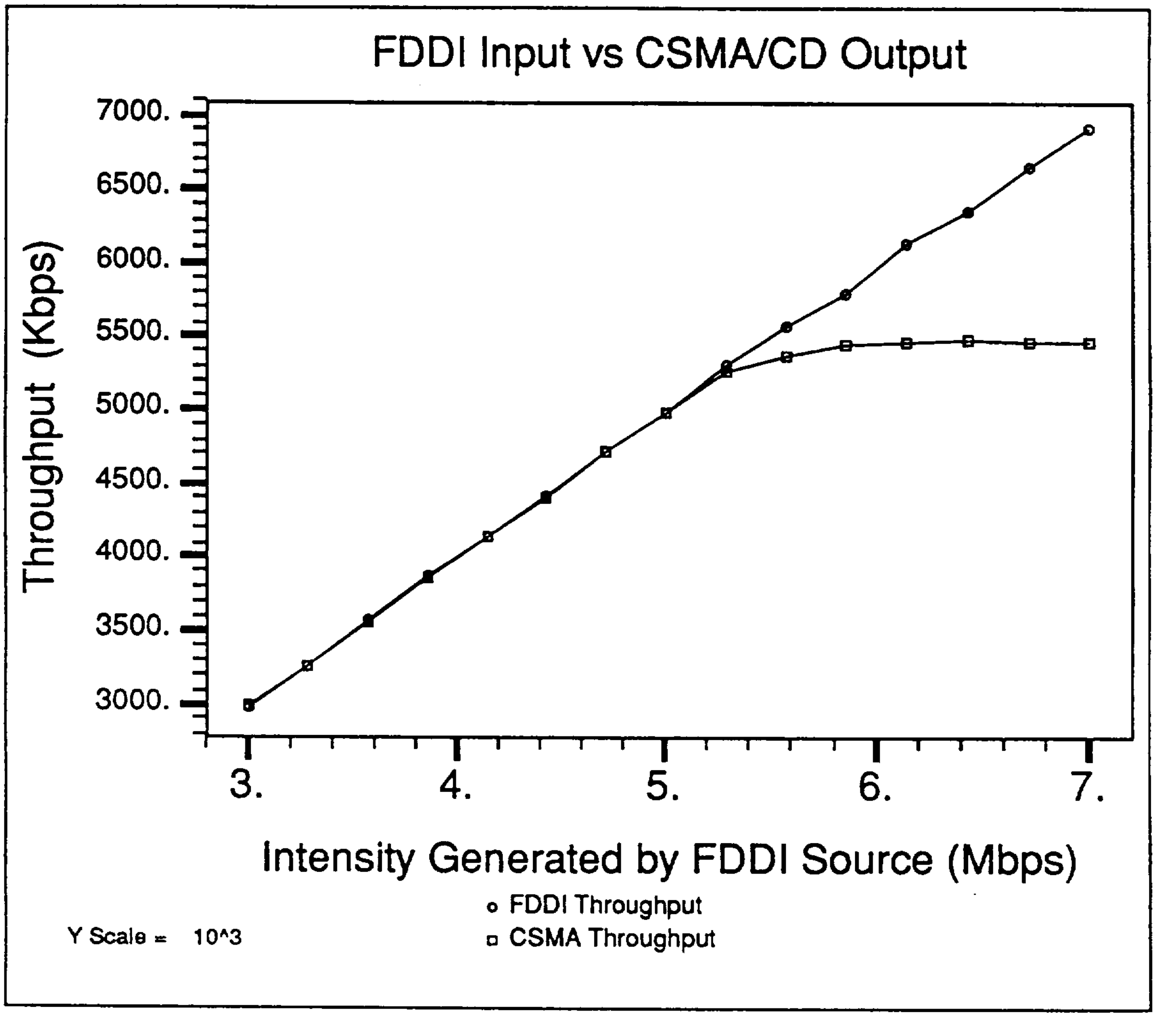


Figure 15. Plot showing the result of the FDMMIM forwarding test.

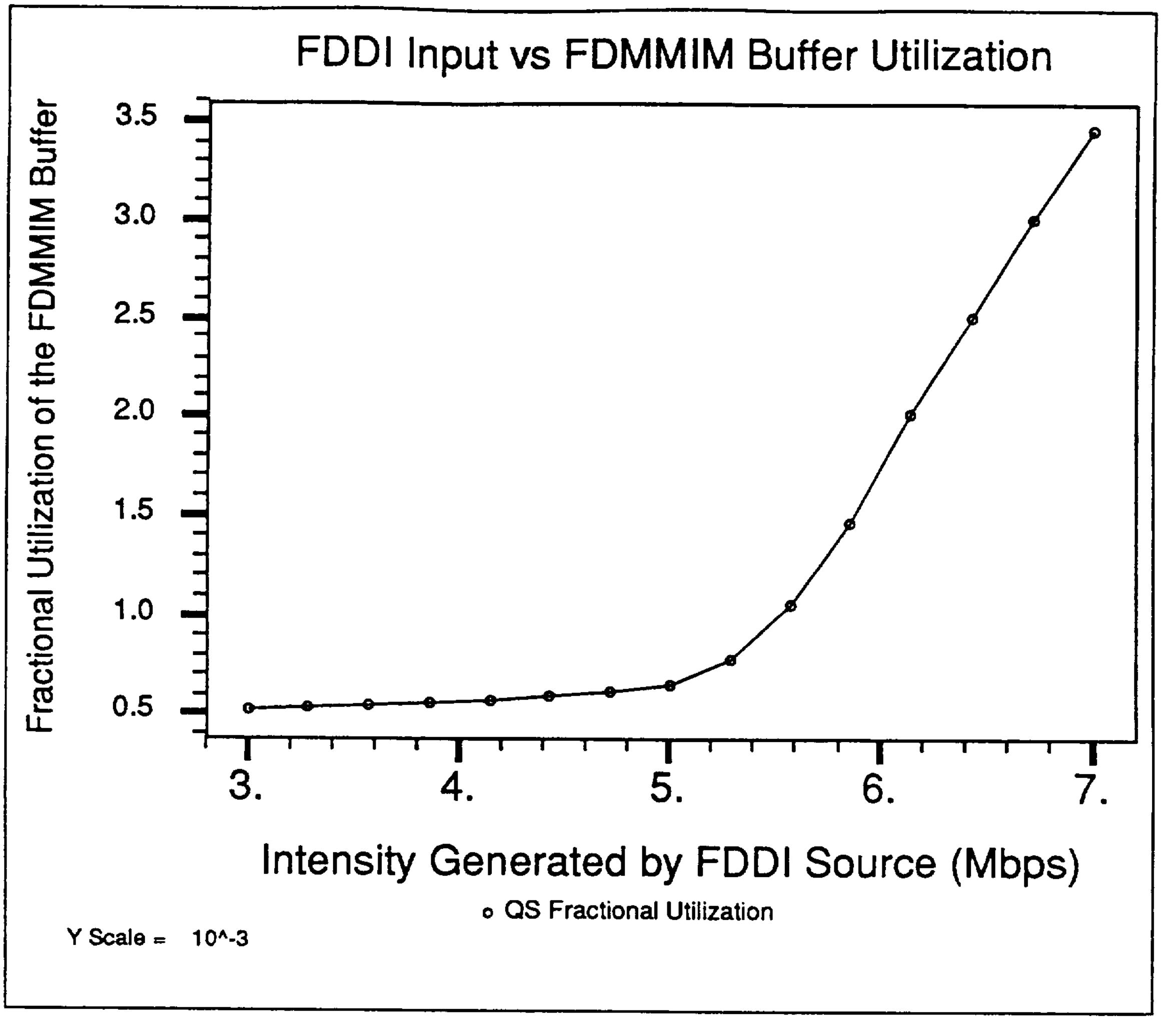


Figure 16. Plot showing the FDMMIM buffer utilization

# CHAPTER VII

# ANALYSIS AND CONCLUSIONS

This chapter discusses some of the conclusions that have been drawn from the research and experimentation. Although much time and effort was put into the research, there are still areas that should be examined in more detail. These areas are discussed in the following sections.

## First Objective

The first objective of this project was to research a Cabletron hub to determine operating characteristics and performance measurements for the hub. Once these measurements were known, a software implementation of the hub was to be designed using Comdisco's BONeS application.

This objective was successfully completed. Using performance measurements reported by Cabletron Inc., it was possible to derive a software model that produced the same results as the actual hardware devices operating under the same network conditions.

Tests were conducted on the software models to verify their operation. Both the FDMMIM and the EMME modules produced the values expected. From the results it was possible to ascertain that under normal operating conditions, both the FDMMIM and the EMME could filter packets as fast as the protocols could deliver them. When forwarding, however, data may need to be buffered for later processing.

## Second Objective

The second objective of the project was to use the developed models in the simulation of the network at the ASRM site. This objective was not completed. The time required to run simulations under BONeS is on the order of days and weeks and therefore requires more time for further testing.

It is possible, however, to predict the outcome by examining the results of the tests that were performed for the first objective. During the first objective, it was shown that both the FDMMIM and the EMME modules can filter packets as fast as the protocols can deliver the packets. Knowing this, it can be said that the Cabletron hub will not be overrun by the protocols when filtering is involved. When the modules are required to forward packets however, the data may indeed be buffered for later processing. Simulations must therefore be performed to determine if the load placed on the modules during operation will produce a significant amount of buffering. The tests from the first objective indicate that a very high network load is required for an extended length of time in order to fill the buffers up even one percent.

## Future Work

There are still areas of this research that need to be studied in more detail. Now that models for the EMME and the FDMMIM have been developed and tested, models for the other media interface modules should also be developed and tested. Although these modules only introduce a fixed delay in the path of a packet, this delay is part of the overall delay of the packet while it is in the network. For the ASRM site, this delay has to be kept to a minimum for the critical networks.

Once the other media modules have been developed and refined, they should be used with the EMME and the FDMMIM modules to build a completed hub. This hub should then replace the existing hub modules in the ASRM simulation. This should give an accurate description as to whether or not the delays caused by the buffering will be a problem. It should also indicate whether or not the buffers in the bridging modules might possibly become full, thereby causing a loss of data.

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# APPENDIX A

# PROJECT CONTRACT

**MCS Project Contract**
**for**
**James F. Dement**
**October 22,1993**

**Project Title.**

Development of an object oriented model to represent the functionality of a Cabletron Hub.

**Project Description.**

Network protocols such as FDDI and Ethernet place restrictions on how networks using these protocols can be constructed. Restrictions such as a maximum number of nodes allowed, or the maximum distance between two nodes, severely limits the topologies available to network designers. To overcome the restrictions of distance and number of nodes, today's network designers utilize what is commonly referred to as a network hub.

This project involves the development of an event-driven, objected-oriented software model and simulation of a hub manufactured by Cabletron, Inc.. Cabletron hubs can be populated with many different modules ranging from bridges to media interfaces for up to seven different types of physical media. Therefore, this project will center around the modules used in the Cabletron hubs that are currently being used by NASA's ASRM facility in Iuka, Mississippi.

The model of the hub will be developed using Comdisco's Block Oriented Network Simulator (BONeS). Using BONeS and the developed model, it will be possible to simulate the response and throughput of different network configurations under different operating conditions. Effects of traffic intensity or packet lengths can be studied without having to actually build the network. Other parameters such as the size of buffers or the delays through bridges can also be varied and their effects studied.

**Deliverables.**

1. Working prototype of the object oriented model.
2. Technical documentation. This will include technical characteristics that were considered for implementation and explanations of any assumptions.
3. User's Manual. This will describe how the models are to be connected and used when developing a network using BONeS.

James F. Dement

James F. Dement Student

Wayne D. Smith

Dr. Wayne D. Smith Project Director

Robert Moorhead

Dr. Robert J. Moorhead Committee Member

Rainey Little

Dr. Rainey Little Committee Member

# APPENDIX B

# BLOCK DIAGRAMS OF BONES MODULES

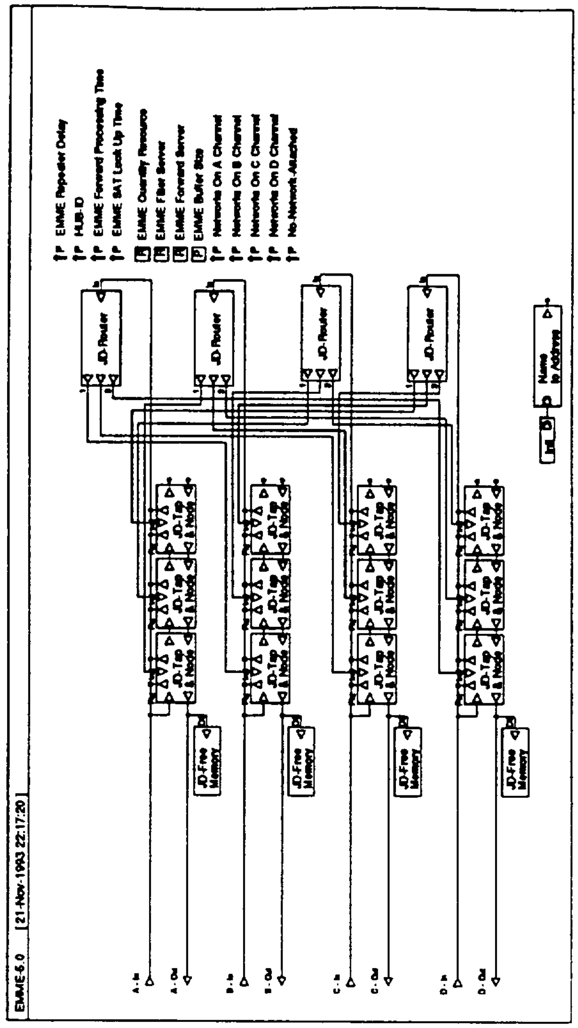

Figure 17. Block diagram of the EMME module

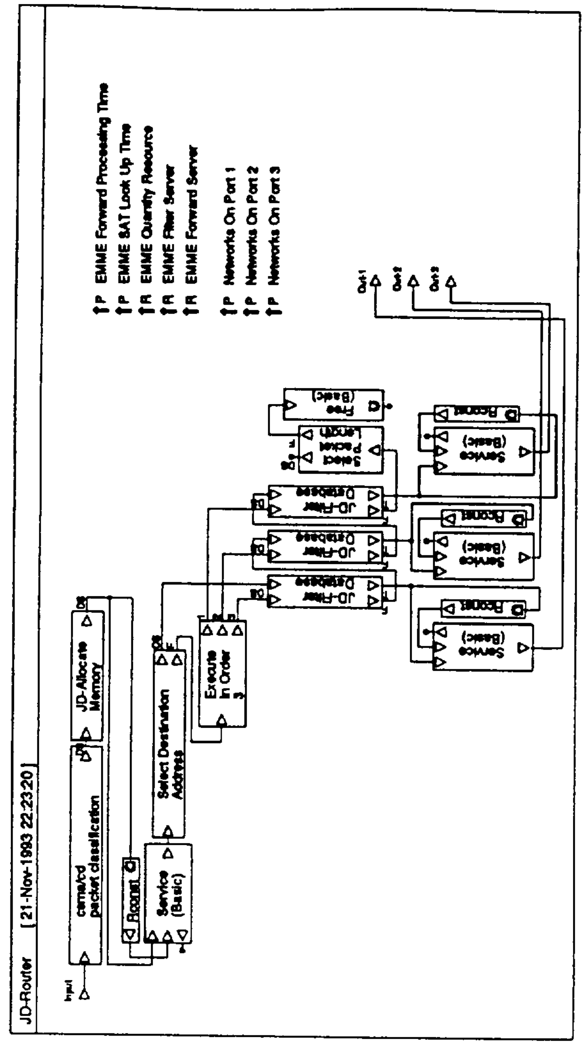


Figure 18. Block diagram of the EMME router

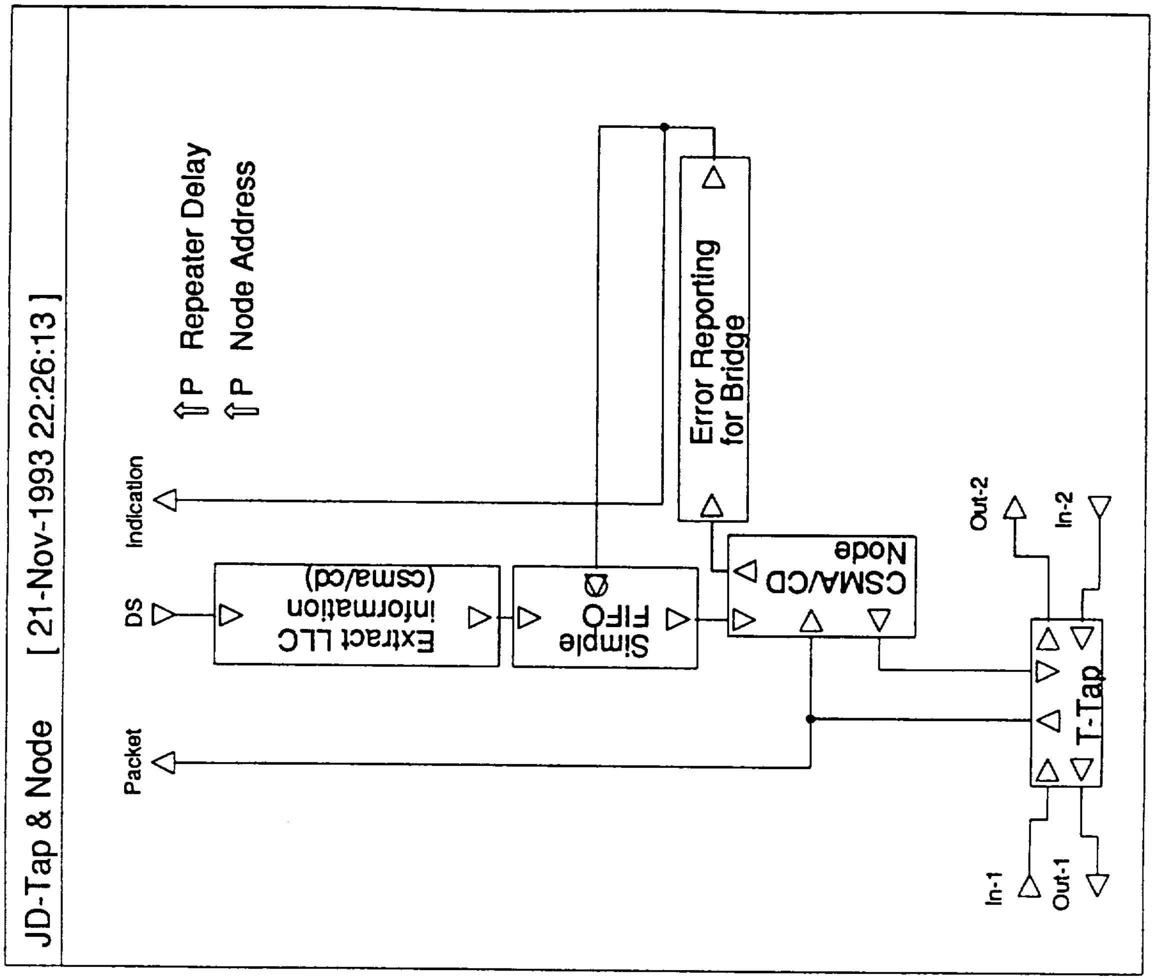


Figure 19. Block diagram of the EMME transmitter node

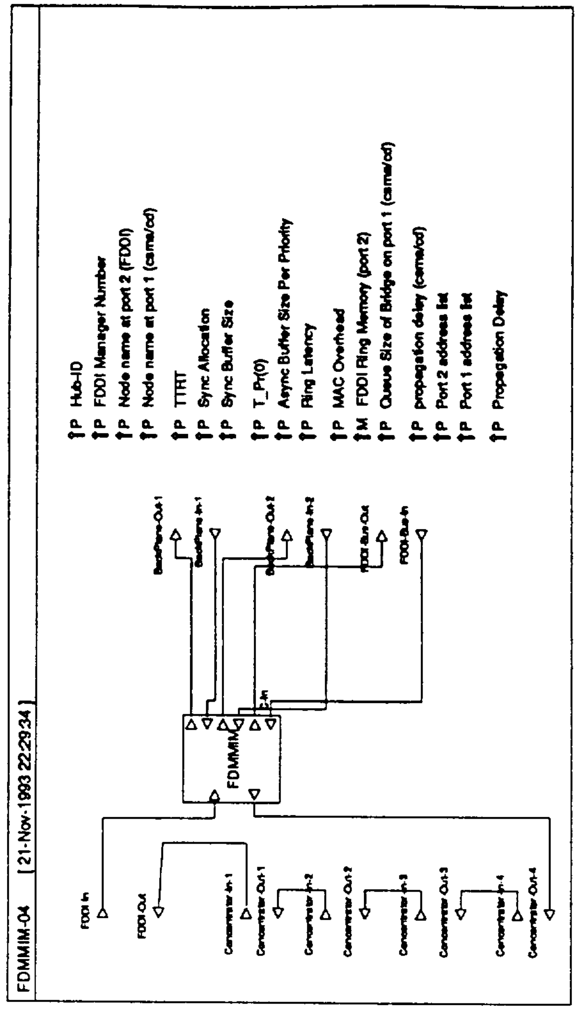


Figure 20. Block diagram of the FDMMIM-04 FDDI concentrator module

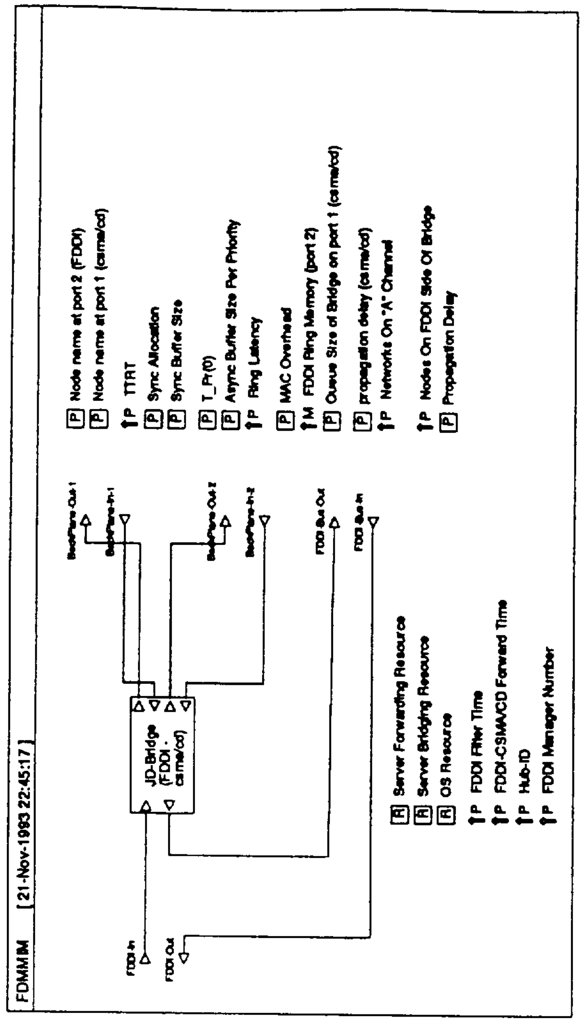


Figure 21. Block diagram of the FDMMIM module

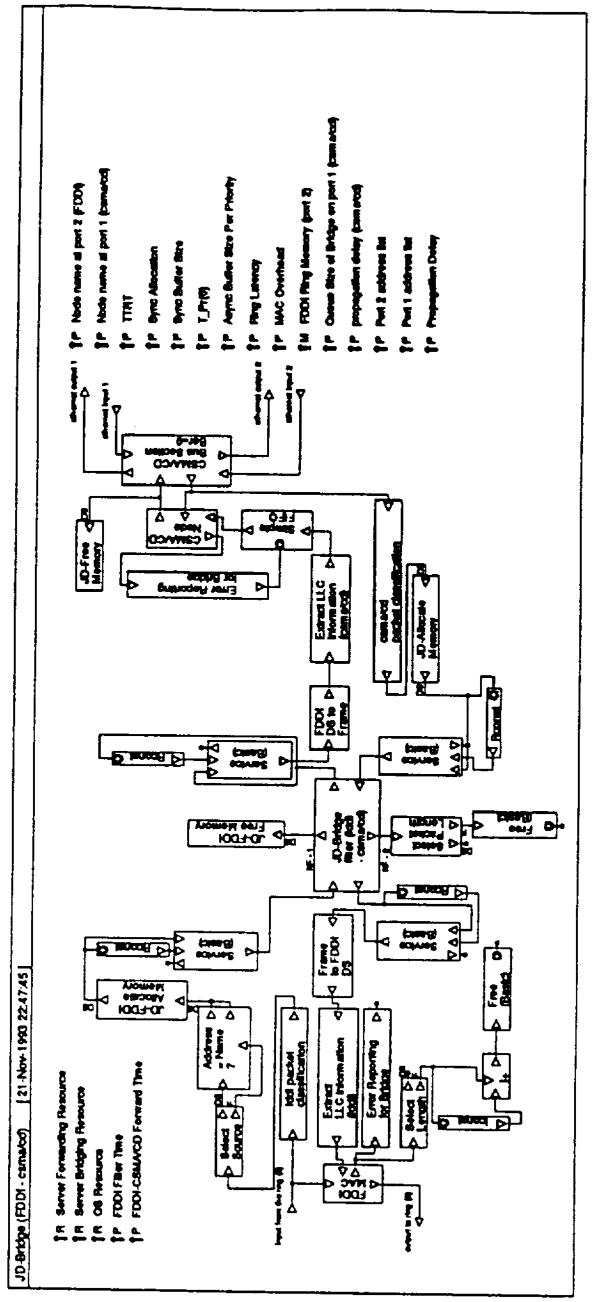

Figure 22. Block diagram of the FDDI - CSMA/CD bridge

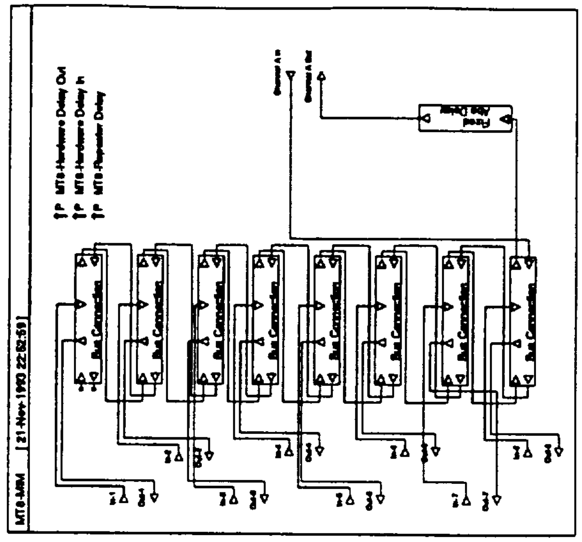

Figure 23. Block diagram of the MT8-MIM media interface module